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An Approach to Secure Future Food

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Chapter 1
Introductory Synopsis of the Natural Resources Involved in Food Production

Introduction

Agriculture has the ability to provide food with high nutrition value, as well as it can provide income to purchase food. There is a huge link between agriculture and food security. Achieving food security requires adequate food availability, access, and use. Sustainable use of natural resources, namely soil and water, in addition to weather and energy, can provide food for the growing population. All these natural resources are fundamental to the structure of economical agricultural systems. Attaining food security situation in a country requires the optimum use of soils, water, and energy to produce crops. Not only optimum use of natural resources, but also sustainable use is required. Farm activities can have major impacts on the quality and availability of these resources (García-Orenes et al. 2013).

Soil Management for Higher Food Production

Soils, as an agricultural natural resource, is the basis for agriculture and the medium, in which nearly all food-producing plants grow. Soil is a very complex system. It may be described as a multicomponent and multifunctional system (Kibblewhite et al. 2008). Soils are originated depending on several factors, such as parent material, climate, and topography, which largely determine the dominant physical and chemical properties of these soils. These properties are often altered by agricultural interventions, such as drainage, irrigation, use of lime to alter soil reaction, and additions of plant nutrients (Van-Camp et al. 2004).

Soil management is fundamental to all agricultural systems, yet there is evidence for widespread degradation of agricultural soils in the form of erosion, loss of organic matter, contamination, compaction, increased salinity, and other harms (European Commission 2002). Soil management has an important influence on microbial soil

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properties (García-Orenes et al. 2013). Soil microbes modify soil structure by aggregating both mineral and organic constituents via production of extracellular compounds with adhesive properties. Such compounds are produced by bacteria and fungi as a feeding mechanism, as protective coatings against desiccation, and as a means of attaching to surfaces the aggregation of soil constituents (Bhuyan et al. 2014). Different agricultural management practices influence soil microorganism and soil microbial processes through changes in the quantity and quality of organic residues in the soil (García-Orenes et al. 2013). Unsuitable land management can lead to a loss of soil fertility and a reduction in the abundance and diversity of soil microorganisms (Caravaca et al. 2002).

Water Management for Higher Food Production

Water is considered the most critical natural resource for sustainable development in most areas of the world. Globally, irrigation accounts for about 60% of total freshwater withdrawals and 80% of total freshwater consumption (Döll et al. 2014). Estimates of total water withdrawal for irrigation range from 2217 to 3185 km^3/year (Hoogeveen et al. 2015). Irrigation is used to reduce crop drought stress by compensating for low precipitation; thus, it is important for higher crops production. Furthermore, in many regions, irrigation is required to grow an additional crop in the dry season and, therefore, helps to increase land productivity (Siebert et al. 2015). Crops yield is, therefore, higher in irrigated agriculture than in rain-fed agriculture, usually by a factor of two or more (Siebert and Döll 2010).To achieve this gain in agricultural production, large volumes of freshwater are consumed, and consequently, irrigation represents the largest anthropogenic global freshwater use (Siebert et al. 2015).

The efficiency of the irrigation water application is very low, since only 55% of the water is used by the crops (Chartzoulakis and Bertaki 2015). To ensure water supply for irrigation, a large infrastructure of man-made reservoirs, channels, pumping networks, and groundwater wells are required. These infrastructures are markedly modifying global freshwater resources, negatively impacting ecologically rivers flow (Steffen et al. 2015), and depleting groundwater (Döll et al. 2014). To overcome water shortage for agriculture, it is essential to increase water use efficiency and to use marginal water (reclaimed, saline, drainage) for irrigation (Chartzoulakis and Bertaki 2015).

Application of surface irrigation to crops results in using large amount of irrigation water. The application efficiency of surface irrigation system is usually between 55 and 60% (Abou Zeid 2002). Improving an irrigation system's efficiency can save both water and energy. An optimized irrigation plan could use the minimum required amount of irrigation and minimize loss deep to soil water table. Changing surface irrigation system to higher efficiency system, namely sprinkler or drip system, will result in reducing the quantity of irrigated water, and consequently, the energy required to distribute the water will likewise be reduced. Additionally, it reduces leaching of fertilizers to groundwater, thus reduces condemnation. Thus, the current situation of water scarcity that faces Egypt creates challenges for agricultural scientists to manage water properly, taking into consideration water resources conservation.

Weather Manipulation for Higher Food Production

The weather of a certain region plays an important role in crop production. Weather variability driven by major inter-annual-scale climate modes has been playing a key role by often leading to droughts and decrease in crop yields that could further result in famine in some food insecure regions (Iizumi et al. 2014). For example, Egypt experiences heat wave in February, annually, resulted in losses in wheat productivity (Taha 2012). Both weather and climate influence all components of crop production, include cropping area (area planted or harvested) and cropping intensity (number of crops grown within a year), whereas crops growing season and required irrigation water for crops are dependent on weather conditions. Determination of the required irrigation water for a growing crop depends on the calculation of the evapotranspiration (ETo). Evapotranspiration includes solar radiation, temperature, relative humidity, and wind speed. It is a combination of two processes: water evaporation from soil surface and transpiration from the growing plants (Gardner et al. 1985). Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide energy for evaporation, whereas solar radiation, air temperature, air humidity, and wind speed should be considered when assessing transpiration (Allen et al. 1998). Consequently, crops growth periods, crops water requirements, and irrigation scheduling are dependent on weather conditions.

One of the suggestions to ease the process of improving water management to face water scarcity is to divide Egypt into agro-climatic zones to ease. A region can be divided into agro-climatic zones based on homogeneity in weather variables that have greatest influence on crop growth and yield (FAO 1979). Thus, agro-climatic zone is a land unit in terms of major climate, superimposed on length of growing period, i.e., moisture availability period (FAO 1983). There were several attempts in Egypt to develop agro-climatic zones. The earliest one was the division of Egypt into three main agro-climatic zones, i.e., Lower Egypt, Middle Egypt, and Upper Egypt. However, this classification was more administrative than climatic. Eid et al. (2006) compared the annual ETo values for each governorate. When the difference between ETo values of several governorates was less than 5%, they grouped together in one zone. Thus, they defined nine agro-zones in Egypt (Fig. 1.1).

On the other hand, Medany (2007) developed agroecological zones using regression equations to predict ETo for a certain zone using average temperature and month number in the year. He distinguished six zones: (1) North Delta (Dakhlia, Gharbia, Damietta, and Kafr El Sheikh); (2) West Delta (Alexandria and Behira governorates); (3) Middle Delta, (Ismailia, Kalubia, Minofia, Port Said, Sharkia governorates); (4) South Delta (Giza, Cairo, Beni Suef, and Faiyum governorates); (5) Middle Egypt (Sohag, Qena, Assuit, and Minia governorates); and (6) Upper Egypt region (Aswan governorate).

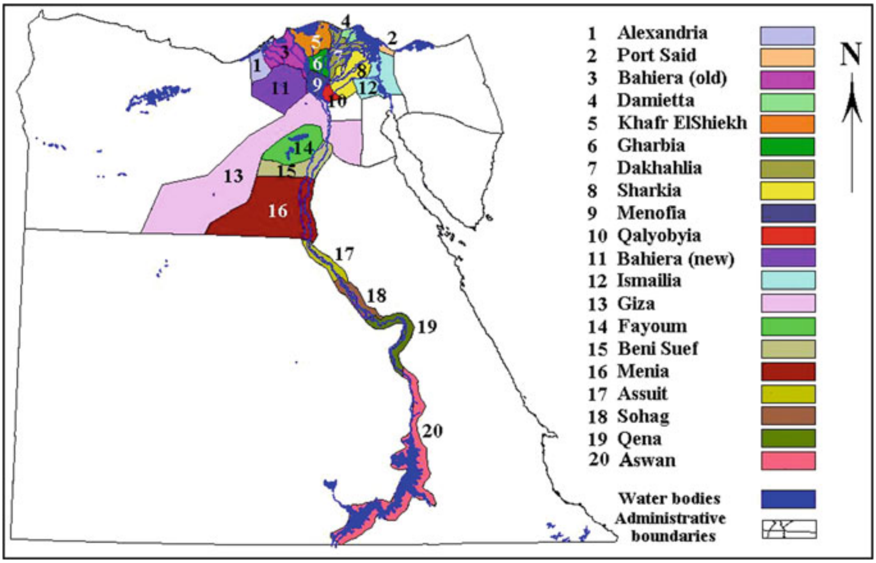

Fig. 1.1 Map of the agro-climatic zones of Egypt. *Source* Eid et al. (2006)

A more recent classification was published by Khalil et al. (2011), where CROPWAT model (FAO 1992) was used to calculate ETo using 10-year weather data (1997–2006) for 20 governorates in Egypt. Their results indicated that there were eight agro-climatic zones (Fig. 1.2).

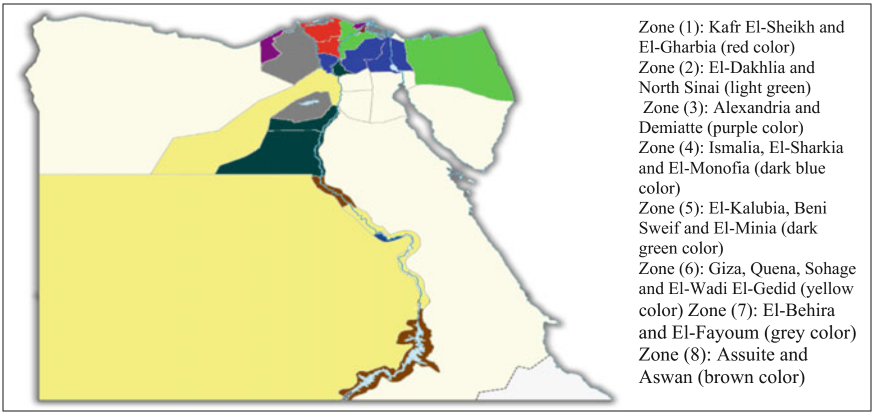

Fig. 1.2 Agro-climatic zones of Egypt using 10 years of ETo (1997–2006). *Source* Khalil et al. (2011)

The problem with that classification is the inclusion of one governorate cultivated under rain fed (North Sinai) and another governorate cultivated using groundwater (El-Wadi El-Gedid). In addition, the soil of these two governorates is sandy, whereas the soil of the other governorates is clay.

Furthermore, Noreldin et al. (2016) used 30-year ETo data from 1985 to 2014 calculated by BISm model (Snyder et al. 2004) to divide Egypt into seven agro-climatic zones in the Nile Delta and Valley governorates only. In that methodology, monthly means of weather data for 10 years were calculated for each governorate. Analysis of variance was used, and the means were separated and ranked using least significant difference test ($LSD_{0.05}$). The results distinguished seven agro-climatic zones (Table 1.1).

Lastly, Ouda and Noreldin (2017) used BISm model (Snyder et al. 2004) to calculate ETo values for 20 years from 1995 to 2014 and for 10 years from 2005 to 2014 and developed agro-climatic zones for Egypt in each time interval. Zoning using 10-year values of ETo resulted in five agro-climatic zones only and higher values of ETo in each zone, compared to 20-year and 30-year ETo values. Table 1.2 shows the five agro-climatic zones developed by Ouda and Noreldin (2017).

Figure 1.3 illustrates the five agro-climatic zones developed by Ouda and Noreldin (2017).

Table 1.1 Agro-climatic zones of Egypt as determined using 30-year weather data

Zone number	Governorate	ETo (mm/day)
Zone 1	Alexandria	4.520
Zone 2	Demiatte	4.687
	Kafr El Sheik	4.677
	El-Dakahlia	4.700
Zone 3	El-Behira	5.084
	El-Gharbia	5.063
Zone 4	El-Monofia	5.176
	El-Sharkia	5.246
	El-Kalubia	5.348
	Giza	5.410
	Fayom	5.548
Zone 5	Beni Sweif	5.681
	El-Minia	5.740
	Assuit	5.810
	Sohag	5.881
Zone 6	Qena	6.002
Zone 7	Aswan	6.167
Mean		5.338
$LSD_{0.05}$		0.146

Source Noreldin et al. (2016)

Table 1.2 Agro-climatic zones of Egypt classification using 10-year of ETo (2005–2014)

Zone number	Governorate	ETo (mm/day)
Zone 1	Alexandria	4.279
	Kafr El Sheik	4.852
Zone 2	Demiatte	5.123
	El-Dakahlia	5.344
	El-Behira	5.192
	El-Gharbia	5.125
Zone 3	El-Monofia	5.800
	El-Sharkia	5.869
	El-Kalubia	5.964
	Giza	5.701
	Fayom	5.587
Zone 4	Beni Sweif	6.139
	El-Minia	6.140
	Assuit	6.122
	Sohag	6.127
Zone 5	Qena	6.480
	Aswan	6.600
Average		5.673
Range		2.321
$LSD_{0.05}$		0.217

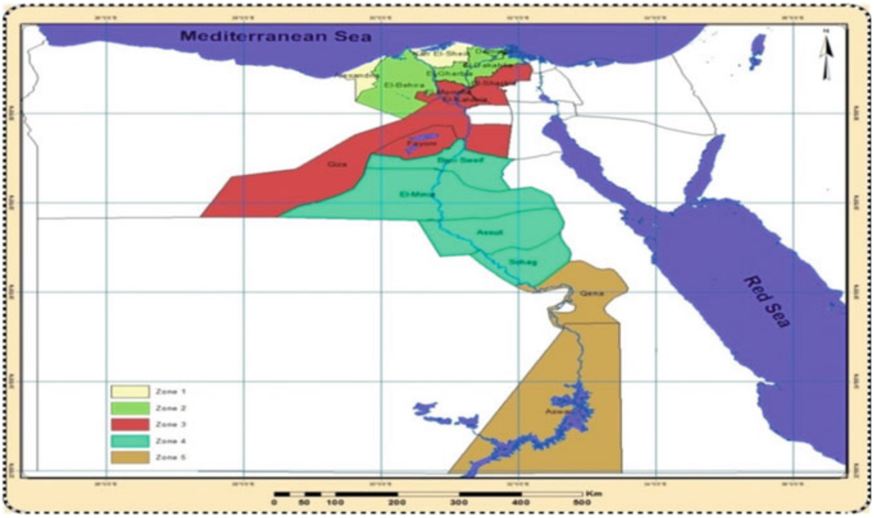

Fig. 1.3 Map of the agro-climatic zones of Egypt using 10-year of ETo values (2005–2014). *Source* Ouda and Noreldin (2017)

The Necessity of Crop Rotation

The issue of food gaps problems ais occupying great importance taking into consideration the steady increase in population of Egypt, as well as the demand on major food commodities, and the lack of resources (Hafez et al. 2011). Currently, in Egypt, there is a gap between production and consumption of cereal crops, namely wheat and maize, where the gap is 45 and 45%, respectively (Ouda and Zohry 2017; Zohry and Ouda 2017a). As reported by Ministry of Agriculture and Land Reclamation in Egypt, there is a gap in the production of oil crops around 97%, where the cultivated area of sunflower and soybean is very low. Furthermore, there is a gap between sugar crops production and sugar consumption around 32%, where the cultivated area of sugarcane and sugar beet is not enough to attain self-sufficiency of sugar. Additionally, there is a gap in forage crops production, especially in the summer around 90%. Lastly, there is a gap in legume crops, especially faba been. This gap resulted from the current expansion in sugar beet cultivated area on behalf the cultivated area of faba bean resulted in 65% production–consumption gap in faba bean (Zohry and Ouda 2017b).

Implementing crop rotations in Egypt could be a solution to broaden food availability and increase food security. Crop rotation is the production of different economically important plant species in recurrent succession on a particular field or group of fields (Bruns 2012). The benefit of crop rotations is well accepted in traditional farming approaches, as well as supported by scientific knowledge (Bennett et al. 2012). Crop rotation means changing the type of crop grown on a particular piece of land from year to year. Crop rotation is one of most effective agricultural control strategies. It involves arrangement of crops planted on same field, where the succeeding crops should belong to different families (Huang et al. 2001). In the crop rotation, alternate deep and shallow rooting crops improve soil structure and aeration. In addition, alternate crops with large and small root biomass result in increase the organic matter remaining in the soil for soil microbial and macro-faunal populations. Furthermore, rotated N2-fixing and N-demanding crops attempt to meet farm's N demands from within the system (Malik 2010). Liu et al. (2005) reported that continuous cropping of wheat, corn, and soybean, compared to a rotation, reduced soil C and N contents at all depths of the soil profile. Some of the general benefits of using crop rotations are to improve or maintain soil fertility, improve soil structure (Raimbault and Vyn 1991); increased soil organic matter levels (Bremer et al. 2008) and enhanced mycorrhizal associations (Johnson et al. 1992). Crop rotation reduces the spread of pests, which provides better weed control and interrupts insects and disease cycles (Karlen et al. 1994).

Climate Change Confine Food Production

Climate change, although it is a global phenomenon, its impacts are more pronounced in the developing countries, due to their greater vulnerabilities and lesser ability to adapt. These developing countries are agriculture-based economies, which are affected mostly due to direct exposure to nature (Mendelsohn 2014). Climate change will affect crop productivity and can thus cause food security problems (Kirby et al. 2016). Climate change negatively affects the productivity of the agriculture sector, its stability, and other components of the food system, including storage, access, and utilization (Wheeler and Von Braun 2013). Climate change will affect food security, either directly or indirectly causing stress on food production (Brown and Funk 2008). Direct contribution of climate change will be through changes in agroecological conditions especially the patterns and productivity of crop, whereas indirect contribution of climate change will be the interruption in growth resulted in yield losses (Vermeulen et al. 2012).

In conclusion, this book will tackle the issue of using crop rotations to increase food production. Crop rotations have a positive effects on soil physical, chemical, and biological properties, thus on soil fertility. It can control pests and weeds, it can increases land productivity, and it can diminish food gaps. Thus, crop rotation is the approach to secure food for the growing population. In the future under climate change, crop rotations can protect the soil from degradation, which could prevent the reduction in food production.

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Chapter 2
Irrigation Scheduling to Maximize Water Utilization of the Crop Rotation

Introduction

The high demand for freshwater creating an unprecedented need for efficient water uses in irrigated agriculture. To attain that, exact or correct irrigation water amount and correct timing of application should be adopted. Irrigation scheduling has, conventionally, aimed to achieve an optimum water supply for better productivity, with soil water content being maintained close to field capacity (Tariq and Usman 2009). Thus, the aim of irrigation scheduling is to maximize yield, enhance irrigation efficiency, and improve crop quality by applying the exact amount of water needed by the crop, or to replenish the soil moisture to the desired level (Ali 2010).

Irmak and Mutiibwa (2010) stated that "evapotranspiration in agro-ecosystems is the sum of two terms: (1) transpiration, in which water entering the plant roots is carried to stems and leaves for building plant tissue via photosynthesis and then passed through the leaves of the plant into the atmosphere, and (2) evaporation, which is water evaporating from soil, water surfaces, or from plant leaf surfaces holding water droplets from rain, irrigation, or dew formation." Thus, transpiration by the plant results in water moves from the roots to the surrounding atmosphere in the form of very small water vapor particles. This movement within or from a field is derived by climatic factors (Irmak and Mutiibwa 2009). Air temperature, solar radiation, relative humidity of air, and wind speed are the primary driver for ETo (Allen et al. 1998). ETo increases with increasing air temperature (maximum and minimum) and solar radiation (or sunshine duration), which are the two primary drivers of ETo (Allen et al. 1998). Decreasing relative humidity of the air surrounding the leaves results in higher ETo because the demand for water vapor by the atmosphere surrounding the leaf surface increases (Irmak and Irmak 2008). Furthermore, high wind speed and direction usually result in an increase in ETo (Irmak and Mutiibwa 2009).

Several equations exist in the literature for calculating ETo. However, the FAO Penman–Monteith method has been considered the universal standard to estimate ETo (Allen et al. 1998). Many researches, nationally (Khalil et al. 2011; Noreldin

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et al. 2016; Ouda and Noreldin 2017) and internationally (McVicar et al. 2007; Buttafuoco et al. 2010; and Song et al. 2010), carried out analysis of using FAO Penman–Monteith method. They calculated ETo from the point of view of its spatial or temporal distribution. Furthermore, comparison between FAO Penman–Monteith with other methods of calculating reference evapotranspiration was done (Maulé et al. 2006; Paltineanu et al. 1999; Sumner and Jacobs 2005; Ouda et al. 2015). Shahidian et al. (2012) indicated that Penman–Monteith method is generally considered as the most reliable, in a wide range of climates and locations, because it is based on physical principles and it considers the main climatic factors, which affect evapotranspiration.

There is a variable relationship between each weather element and ETo. Khalil et al. (2011) found that a strong relation between ETo and mean temperature, sunshine duration, relative humidity, where correlation coefficient were 0.83, 0.79, and 0.70, respectively, and weak relation between ETo and wind speed, i.e., 0.27. Their analysis was done using averaged weather data from 1997 to 2006 to calculate 10-year mean of ETo valued in 20 governorates in Egypt. Noreldin et al. (2016) analyzed 30-year averages of weather data from 1985 to 2014 in 17 governorates in the Nile Delta and Valley in Egypt, and they found that the values of coefficient of determination (R^2) between ETo and maximum and minimum temperatures, solar radiation, as well as wind speed were 0.91, 0.86, 0.52 and 0.23, respectively. Ouda and Noreldin (2017) used averages of 10-year weather data from 2005 to 2014 to calculate ETo, and they concluded that R^2 values between ETo and mean temperature were 0.79. Moreover, R^2 values were 0.58 and 0.37 between ETo values and solar radiation and wind speed, respectively. That analysis was done on 17 governorates in the Nile Delta and Valley in Egypt.

Recently, there is some evidence in Egypt indicated an increasing trend in ETo values in the past 30-year time interval (1985–2014) (Ouda and Noreldin 2017). Similar trends of increasing ETo values were reported around the world. An increasing trend in ETo values in Taiwan was observed when 48-year time interval of weather data was used in the analysis (Yue et al. 2002). In Northeast Brazil, (Da Silva 2004) reported increase in ETo values, where 30-year time period was used. Burn and Hesch (2007) indicated that there was an increasing trend of ETo values in the northern regions of Canada. An increase by 28% in annual ETo values over Iran was reported during the period 1965–2005 (Dinpashoh et al. 2011). Lastly, there is an increasing trend in the annual ETo values in the agricultural areas of Sanjiang Plain, China, between 1959 and 2013 (Song et al. 2017).

Other researchers around the world reported decreasing trends in ETo values. A decrease by 4% in ETo values across the Tibetan Plateau during the period 1966–2001 was found by Zhang et al. (2017). Decreasing trends in annual potential and actual evapotranspiration were found in most parts of the Haihe River Basin in China during 1960–2002 (Gao et al. 2006). Han et al. (2015) found a decrement of 5% in annual ETo values using 48 years (1961–2008) over entire China. In North China Plain, Song et al. (2017) reported a decreasing trend in ETo values by 5% during 1961–2006.

Water is one of the most important limited natural resources. Irrigation is the main user of water resources in Egypt, where 85% of it is allocated to agriculture. The growing scarcity in water requires maximizing efficiency of water usage. Therefore, proper management of irrigation water and control in its application depths is essential, in order to apply water effectively according to crop needs (Abou Zeid 2002). Although calculation of ETo values is an important tool in determining water needs of different crops (Shahidian et al. 2012), availability of weather elements to calculate it sometimes become an obstacle. Agricultural extension workers need monthly ETo values to guide farmers on when to apply irrigation and how much water needs to be applied. Thus, they use time series of old ETo values, which might or might not be good representations of current weather conditions. Ouda and Noreldin (2017) detected variability in the weather elements, as well as ETo values in the past 10 years 2005–2014, compared to the past 20-year or 30-year intervals, which imply obligation to determine the number of annual ETo data that contains less variability.

Thus, the objective of this chapter was to determine how many years of past weather data is required to develop an estimate of ETo to be used in irrigation scheduling in the prevailing crop rotations in the five agro-climatic zone of Egypt.

Methodology

Description of the Agro-climatic Zones of Egypt

The recent classification of Egypt to agro-climatic zones developed by Ouda and Noreldin (2017) was used in this analysis. This classification was done using 10-year averages of ETo (2005–2014). Their results revealed that there are five agro-climatic zones exist in Egypt (Table 2.1).

Figure 2.1 shows the map of the agro-climatic zones in Egypt. This classification was used in our analysis to determine the suitable number of years to calculate ETo values in each zone.

Statistical Procedure

Weather data was collected for 10 years from 2007 to 2016 in each zone. These data contained solar radiation, wind speed, as well as maximum, minimum and dew point temperatures. The mean value over 10 years of each of weather elements was calculated. ETo values were calculated with BISm model (Snyder et al. 2004) using Penman–Monteith equation, as presented in the United Nations FAO Irrigation and Drainage Paper (FAO 56) by (Allen et al. 1998). Annual and seasonal winter and seasonal summer values of ETo were calculated. In Egypt, the winter growing season is between November and April, whereas the summer growing season is between May and October. The calculated annual weather elements and ETo values were individually analyzed to study its spatial and temporal variability and to check whether ETo values decreasing or increasing.

Table 2.1 Agro-climatic zones classification in Egypt using 10-year time interval

Zone number	Governorate	Latitude (°)	Longitude (°)	Elevation above sea level (m)	ETo (mm/day)
Zone 1	Alexandria	31.70	29.00	7.0	4.279
	Kafr El-Sheik	31.07	30.57	20.0	4.852
Zone 2	Demiatte	31.25	31.49	5.0	5.123
	El-Dakahlia	31.03	31.23	7.0	5.344
	El-Behira	31.02	30.28	6.7	5.192
	El-Gharbia	30.47	32.14	14.8	5.125
Zone 3	El-Monofia	30.36	31.01	17.9	5.800
	El-Sharkia	30.35	31.30	13.0	5.869
	El-Kalubia	30.28	31.11	14.0	5.964
	Giza	30.02	31.13	22.5	5.701
	Fayom	29.18	30.51	30.0	5.587
Zone 4	Beni Sweif	29.04	31.06	30.4	6.139
	El-Minia	28.05	30.44	40.0	6.140
	Assuit	27.11	31.06	71.0	6.122
	Sohag	26.36	31.38	68.7	6.127
Zone 5	Qena	26.10	32.43	72.6	6.480
	Aswan	24.02	32.53	108.3	6.600
Mean					5.673
Range					2.321
$LSD_{0.05}$					0.217

Source Ouda and Noreldin (2017)

Descriptive statistical analysis for the weather elements, as well as ETo (annual, winter, and summer) in the five agro-climatic zones, was performed to calculate maximum and minimum values, the range between them and the mean. Coefficient of variation (CV%) was also calculated, which is defined as the ratio of the standard deviation to the mean. Sendicor and Cochran (1980) stated that the higher the coefficient of variation, the greater the level of dispersion around the mean. Furthermore, coefficient of determination (R^2) between each weather element and ETo was calculated to test the strength of the relationship between them (Draper and Smith 1987). The deviation from the mean value of seasonal winter and summer ETo values was analyzed and graphed with its counterpart value. Furthermore, the analysis determined the suitable time-interval of ETo values in each zone to be used in irrigation scheduling.

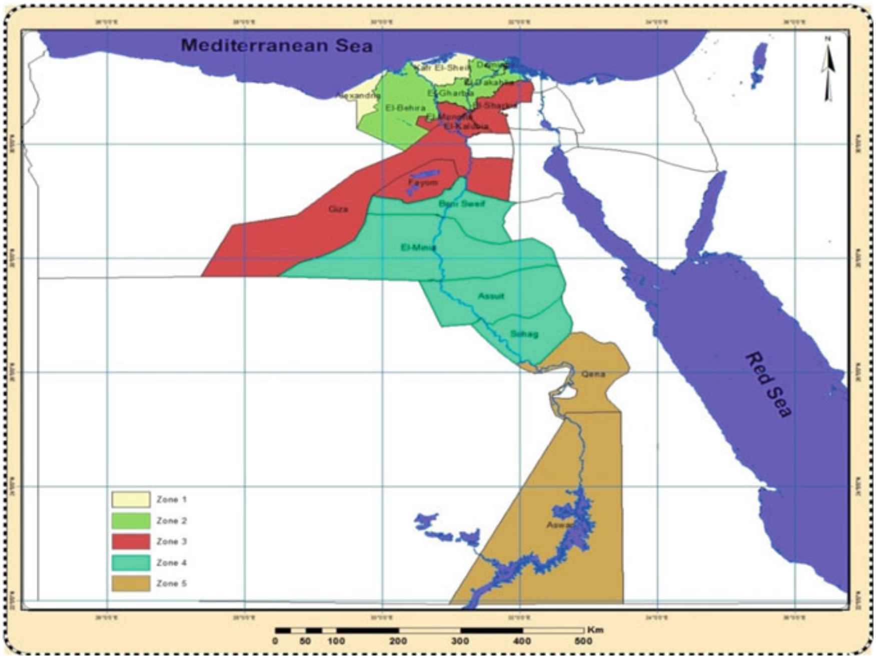


Fig. 2.1 Map of agro-climatic zones of Egypt using 10-year of ETo values. *Source* Ouda and Noreldin (2017)

Validation of the ETo Time-Interval

BISm model (Snyder et al. 2004) was used to schedule irrigation using the suitable time-interval of ETo values in each zone for the crops grown of the prevailing three-year rotation in each agro-climatic zones. Moreover, the calculated values of water requirements for the crops in each crop rotation were compared to its counterpart values calculated using weather data in 2016.

Results and Discussion

Spatial and Temporal Variability of Weather Elements

1. **Solar radiation**

Table 2.2 presents the spatial and temporal variability in annual values of solar radiation in the agro-climatic zones. The results indicated that there was an increasing trend of annual solar radiation values from zone 1 in north Egypt to zone 5 in south

Table 2.2 Spatial and temporal variability in annual values of solar radiation (MJ/m^2/day) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	20.5	20.4	20.1	21.8	22.6
2008	20.9	20.8	21.2	22.5	23.0
2009	20.9	20.8	21.2	22.4	22.9
2010	20.9	20.9	21.3	22.4	22.9
2011	20.7	20.6	20.9	22.5	23.1
2012	20.6	20.7	21.1	22.1	22.7
2013	19.5	19.5	20.7	22.4	22.8
2014	19.3	19.3	20.4	22.2	22.7
2015	18.9	18.9	20.1	22.1	22.6
2016	19.3	19.4	20.4	22.1	22.5
Mean	20.2	20.1	20.7	22.3	22.8
Range	2.0	2.0	1.1	0.7	0.5
CV (%)	3.9	3.8	2.1	1.1	0.8

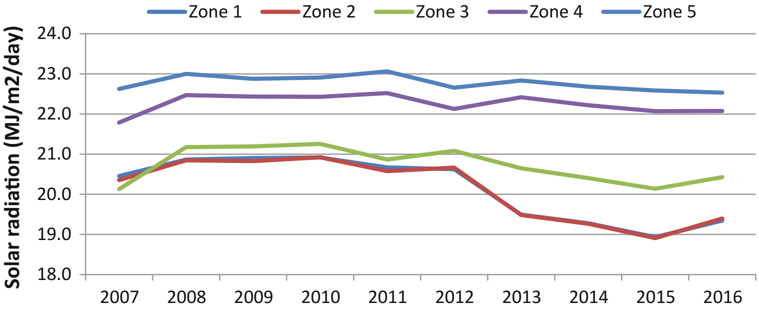


Fig. 2.2 Spatial and temporal variability in the annual values of solar radiation in the studied time interval for the agro-climatic zones of Egypt

Egypt. The mean value of solar radiation in the studied 10-year interval was the highest in zone 5, compared to zone 1 and zone 2. Furthermore, the range value followed a decreasing trend from zone 1 to zone 5, where it was 2.0 MJ/m^2/day in zone 1 and decreased to 0.5 MJ/m^2/day in zone 5. Coefficient of variation (CV%) was the highest in zone 1 and the lowest in zone 5. The above results showed that temporal variability of solar radiation was the highest in zone 1 and the lowest in zone 5. Morsy et al. (2017) stated that, in Egypt, solar radiation decreases gradually from south to north according to the apparent position of the sun and reaches its maximum value in the summer season.

Figure 2.2 illustrates the spatial variability between zones and temporal variability between years for the annual solar radiation values in the five agro-climatic zones of Egypt. The figure showed a decreasing trend starting from 2013 in zones 4 and

Table 2.3 Spatial and temporal variability in annual values of maximum temperature (°C) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	25.0	24.9	28.6	27.4	29.6
2008	27.2	29.9	31.8	29.8	34.0
2009	27.0	29.7	31.5	29.6	33.9
2010	28.5	31.2	33.3	31.9	36.2
2011	26.7	29.3	31.0	29.2	33.5
2012	27.4	30.1	31.7	30.0	34.2
2013	26.0	27.3	30.0	28.1	32.7
2014	26.2	27.5	30.1	28.5	33.0
2015	25.8	27.1	29.7	28.2	32.8
2016	26.4	27.7	30.3	28.6	33.1
Mean	26.6	28.5	30.8	30.9	33.3
Range	3.5	6.4	4.6	4.6	6.6
CV (%)	3.6	6.6	4.3	4.4	5.0

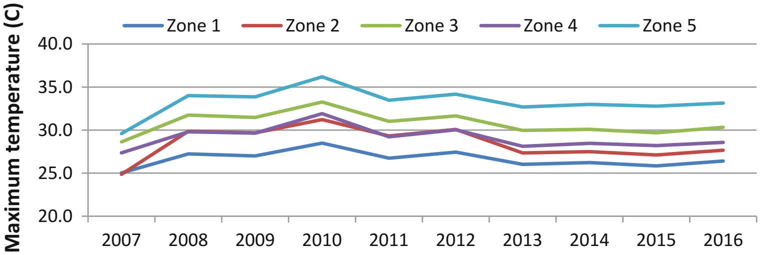


Fig. 2.3 Spatial and temporal variability in annual values of maximum temperature in the studied time interval for the agro-climatic zones of Egypt

5 and increasing trend started in 2015 in zones 1, 2, and 3. It worth noting that the differences between zones 1 and 2 in solar radiation are very low and both values are almost identical.

2. Maximum temperature

There was an increasing trend in annual maximum temperature values from north Egypt represented by zone 1 to south Egypt represented by zone 5. The mean of annual maximum temperature and the range value were the lowest in zone 1 and the highest in zone 5. In addition, the value of CV% for zone 2 was the highest (Table 2.3). Morsy et al. (2017) indicated that maximum temperature in Egypt increases gradually southward in all seasons following the apparent position of the sun.

Spatial variability between the studied zones and temporal variability between the studied time intervals for maximum temperature is shown in Fig. 2.3. In all zones, there was a stable trend started from 2014 to 2016 (Fig. 2.3).

3. Minimum temperature

With respect to annual minimum temperature, it exhibited an increasing trend between the studied years. The lowest mean value was found in zone 4, and the highest value was found in zone 1 (Table 2.4). Morsy et al. (2017) reported that most of Middle Egypt, where zone 4 is located, has the lowest values of minimum temperature in all seasons. Instability in the value of annual minimum temperature between years was expressed by the value of the range and CV%, where both values were the lowest in zone 2. The highest range value was found in zone 5, and the highest CV% value was found in zone 4 (Table 2.4).

Lower temporal variability in annual minimum temperature values existed in the studied time interval. Starting from 2014 to 2016, a stable trend was found for annual minimum temperature values in the five agro-climatic zones (Fig. 2.4).

Table 2.4 Spatial and temporal variability in annual values of minimum temperature (°C) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	17.1	17.2	14.6	12.4	14.8
2008	18.9	18.1	16.0	14.8	17.5
2009	18.9	18.1	16.1	14.9	17.6
2010	19.7	19.0	17.4	16.8	19.7
2011	19.1	18.3	16.1	14.9	17.6
2012	19.4	18.6	16.6	15.7	18.5
2013	17.8	17.6	14.7	13.5	16.3
2014	18.3	18.0	15.2	14.0	16.7
2015	18.2	18.0	15.3	14.0	16.8
2016	18.4	18.2	15.3	14.1	16.8
Mean	18.6	18.1	15.7	14.5	17.2
Range	2.6	1.8	2.8	4.4	4.9
CV (%)	4.2	2.8	5.5	8.4	7.6

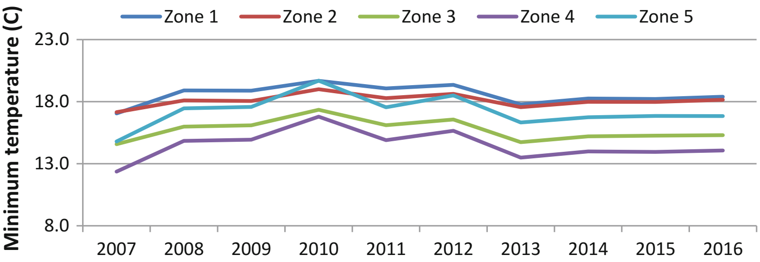


Fig. 2.4 Spatial and temporal variability in annual values of minimum temperature in the studied time interval for the agro-climatic zones of Egypt

4. **Wind speed**

The lowest mean of annual wind speed values was found in zone 3, whereas the highest value was found in zone 1 (Table 2.5). Morsy et al. (2017) reported that there is a strong gradient of wind over northern part of Egypt, as a result of Mediterranean depression. The range value and CV% were the highest in zone 4. The lowest value of CV% was found in zone 1 (Table 2.5).

Figure 2.5 shows medium temporal variability in annual wind speed values in the five agro-climatic zones. The year of 2015 and 2016 witnessed stability in the annual wind speed values.

5. **Dew point temperature**

The annual values of mean dew point temperature followed a spatial decreasing trend, where the highest value existed in zone 1 and the lowest value existed in zone 5.

Table 2.5 Spatial and temporal variability in annual values of wind speed (m/s) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	3.4	3.3	2.4	2.5	2.6
2008	3.4	3.2	2.9	3.4	3.1
2009	3.4	3.2	2.9	3.2	2.8
2010	3.3	3.2	3.0	3.3	2.9
2011	3.2	3.1	2.9	3.3	3.0
2012	3.4	3.2	2.9	3.1	3.0
2013	3.7	3.5	2.9	3.6	3.1
2014	3.3	3.2	2.7	3.4	3.1
2015	3.6	3.4	2.9	3.5	3.3
2016	3.6	3.5	3.0	3.6	3.4
Mean	3.4	3.3	2.8	3.3	3.0
Range	0.4	0.4	0.6	1.1	0.8
CV (%)	3.9	4.2	6.2	9.6	8.0

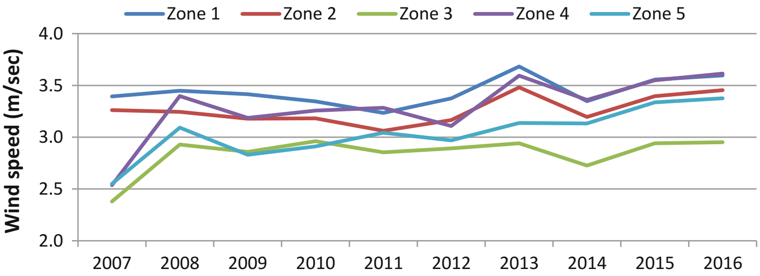


Fig. 2.5 Spatial and temporal variability in annual values of wind speed in the studied time interval for the agro-climatic zones of Egypt

Table 2.6 Spatial and temporal variability in annual values of dew point temperature (°C) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	13.1	13.2	9.1	2.5	−0.2
2008	13.4	12.2	8.9	4.5	2.0
2009	13.4	12.3	8.6	4.1	1.5
2010	14.7	13.6	10.0	6.2	3.8
2011	14.4	13.1	9.8	5.8	3.0
2012	14.8	13.4	9.8	6.2	3.5
2013	13.8	13.1	8.7	3.8	2.0
2014	14.1	13.4	9.4	4.4	2.8
2015	14.0	13.4	9.5	4.6	3.0
2016	14.0	13.4	9.4	4.8	2.9
Mean	14.0	13.1	9.3	4.7	2.4
Range	1.7	1.3	1.4	3.8	4.0
CV (%)	4.0	3.5	5.3	24.9	47.6

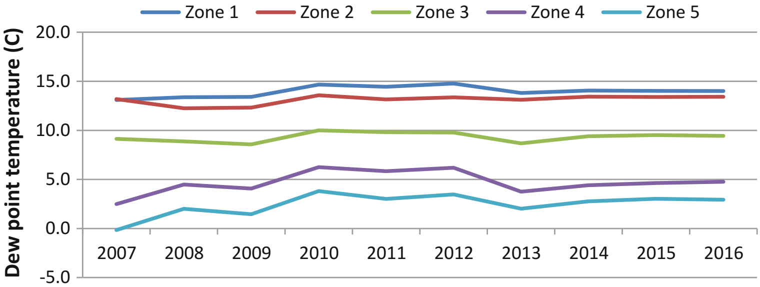


Fig. 2.6 Spatial and temporal variability in annual values of dew point temperature in the studied time interval for the agro-climatic zones of Egypt

Furthermore, the highest value of the range between maximum and minimum values and CV% values were found in zone 5, whereas the lowest values were found in zone 2 (Table 2.6). The results in the table also showed that temporal variability was very high in zones 4 and 5, where CV% was 24.9 and 47.6%, respectively.

Figure 2.6 shows low temporal and spatial variability in the values of annual dew point temperature in the studied time interval in zones 1 and 2, medium variability in zone 3, and high variability in zones 1 and 5. The figure also showed that starting from 2014 to 2016 the value of dew point temperature became stable.

The above results indicated that the value of solar radiation was lower in 2016 than its counterpart value in 2007, whereas the values of the rest of the studied weather elements were higher in 2016 compared to its counterpart values in 2007. Furthermore, spatial variability between zones was expressed by lower value of solar radiation and maximum temperature in zone 1, as well as higher values of minimum temperature, wind speed and dew point temperature, compared to zone 5. Higher temporal variability in solar radiation, maximum temperature, as well as lower temporal variability in minimum temperature, wind speed and dew point temperature existed in zone 2, compared to zone 5.

Spatial and Temporal Variability of ETo

1. Annual ETo values

There is an increasing spatial and temporal trend in the annual ETo values in all the agro-climatic zones. The lowest mean of annual values of ETo was found in zone 1, whereas the highest value was found in zone 5. The range value and CV% were the lowest in zone 1, whereas the highest value of the range was found in zone 5. In addition, the highest value of CV% was found in zone 2 (Table 2.7).

Figure 2.7 shows comparison between annual values of ETo in the five agro-climatic zones. The figure showed that the lowest values existed in zone 1 and the highest value existed in zone 5. The figure also showed that there is a variable trend in the value of annual ETo from 2007 to 2013 in all zones. A steady trend in the value of annual ETo value from 2014 to 2016 was found in all zones, and except for zone 1, ETo values increased in 2016.

Table 2.8 presents the percentage of increase in the value of annual ETo in zones 2, 3, 4, and 5, compared to zone 1. The results in the table indicated that there are increasing trends in the value of annual ETo in zones 2, 3, 4, and 5, compared to zone 1. The table also showed that, in zone 2, percentage of increase in ETo values was the highest from 2008 to 2012. This can be attributed to increasing maximum

Table 2.7 Spatial and temporal variability in annual values of ETo (mm/day) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	4.8	4.7	5.3	5.8	6.4
2008	5.5	6.1	6.6	7.1	8.0
2009	5.4	6.0	6.5	6.9	7.7
2010	5.6	6.2	6.9	7.3	8.1
2011	5.1	5.7	6.3	6.7	7.8
2012	5.3	5.9	6.5	6.7	7.8
2013	5.0	5.3	6.1	6.9	7.7
2014	4.9	5.2	5.9	6.7	7.7
2015	4.9	5.2	5.9	6.7	7.7
2016	5.1	5.2	6.1	6.9	7.8
Mean	5.2	5.6	6.2	6.8	7.7
Range	0.7	1.5	1.6	1.5	1.7
CV (%)	5.2	8.8	7.3	5.9	6.0

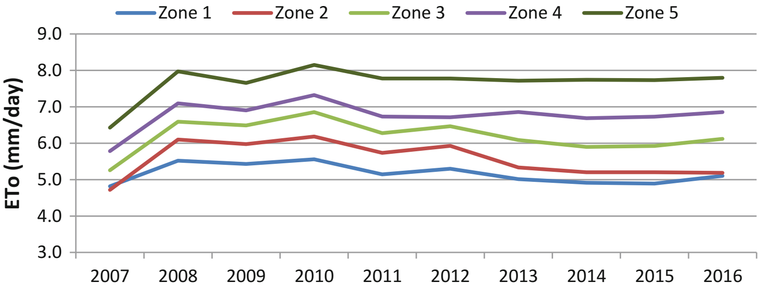


Fig. 2.7 Comparison between annual values of ETo in the five agro-climatic zones of Egypt

Table 2.8 Percentage of increase in annual ETo values between zone 1 and the rest of the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	–	2	9	20	33
2008	–	10	19	28	44
2009	–	10	19	27	41
2010	–	11	23	32	47
2011	–	12	22	31	51
2012	–	12	22	27	47
2013	–	6	21	37	54
2014	–	6	20	36	58
2015	–	6	21	38	58
2016	–	2	20	34	53

temperature levels in these years (Table 2.3). The trend was different in the rest of the zones, where the percentage of increases were variables between the studied years.

2. Seasonal winter values of ETo

Analogues to annual values, seasonal winter ETo values exhibit an increasing spatial and temporal trends. The lowest mean values of seasonal winter ETo were found in zone 1, whereas the highest value was found in zone 5. The range value was the lowest in zone 1, whereas the highest range value was found in zone 4. Furthermore, the CV% value was the highest in zone 2 and was the lowest in zone 5 (Table 2.9).

A comparison between seasonal winter values of ETo in the five agro-climatic zones is presented in Fig. 2.8. The figure showed that the lowest values existed in zone 1 and the highest values existed in zone 5. The figure also showed that there is a variable trend in the value of seasonal winter ETo from 2007 to 2013 in all zones. A steady trend in the value of seasonal winter ETo was found from 2014 to 2016 in zones 2, 4, and 5. Furthermore, an increasing trend of in the value of seasonal winter ETo existed in zones 1 and 3.

Table 2.10 presented the percentage of increase in seasonal winter ETo values between zone 1 and the rest of the agro-climatic zones of Egypt. The results in this table showed increasing trends in the values of seasonal winter ETo in zones 2, 3, 4,

Table 2.9 Spatial and temporal variability in seasonal winter values of ETo (mm/day) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	3.5	3.5	3.9	4.1	5.0
2008	4.2	4.5	4.7	5.1	5.7
2009	4.1	4.3	4.6	5.0	5.6
2010	4.2	4.5	4.9	5.4	6.0
2011	3.6	3.9	4.1	4.6	5.6
2012	3.8	4.0	4.3	4.7	5.7
2013	3.7	3.9	4.4	4.9	5.6
2014	3.6	3.7	4.1	4.8	5.6
2015	3.5	3.7	4.1	4.7	5.6
2016	3.8	3.7	4.4	4.8	5.6
Mean	3.8	4.0	4.3	4.8	5.6
Range	0.7	1.0	1.1	1.2	1.1
CV (%)	7.4	9.2	8.0	7.3	5.3

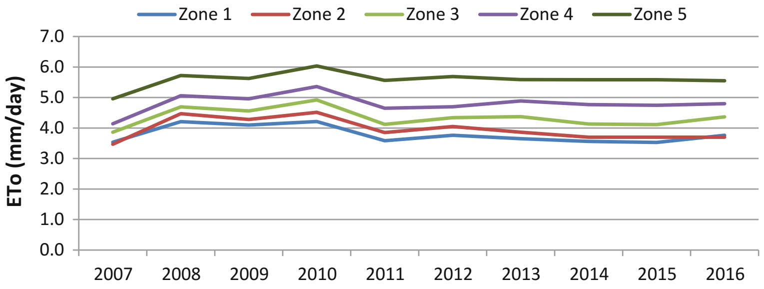


Fig. 2.8 Comparison between winter seasonal values of ETo in the five agro-climatic zones of Egypt

and 5, compared to zone 1. The table also showed that in zone 2, the year of 2016 had the lowest value of percentage of increase. That trend was different in the rest of the zones, where the percentage of increases were variables between the studied years (Table 2.10).

3. Seasonal summer values of ETo

Similar to annual and seasonal winter values of ETo, the same trend was found for the seasonal summer values, where the lowest values were found in zone 1 and the highest value was found in zone 5. The range value was the highest in zone 5, whereas the lowest value was found in zone 1. Furthermore, the CV% value was the highest in zone 2 and was the lowest in zone 1 (Table 2.11).

Figure 2.9 shows similar trends of annual and seasonal summer ETo values, where the lowest values existed in zone 1 and the highest value existed in zone 5. The figure

Table 2.10 Percentage of increase in seasonal winter ETo values between zone 1 and the rest of the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	–	2	9	17	40
2008	–	6	12	20	36
2009	–	4	11	21	37
2010	–	7	17	27	43
2011	–	7	15	30	55
2012	–	8	15	25	51
2013	–	6	20	34	53
2014	–	4	16	34	57
2015	–	5	17	35	58
2016	–	2	16	28	48

Table 2.11 Spatial and temporal variability in seasonal summer values of ETo (mm/day) in the agro-climatic zones of Egypt

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	6.1	6.0	6.6	7.4	7.9
2008	6.8	7.7	8.5	9.1	10.2
2009	6.8	7.7	8.4	8.8	9.7
2010	6.9	7.9	8.8	9.3	10.3
2011	6.7	7.6	8.4	8.8	10.0
2012	6.8	7.8	8.6	8.7	9.9
2013	6.4	6.8	7.8	8.8	9.8
2014	6.3	6.7	7.6	8.6	9.9
2015	6.3	6.7	7.7	8.7	9.9
2016	6.4	6.7	7.9	8.9	10.0
Mean	6.5	7.2	8.0	8.7	9.8
Range	0.8	1.9	2.1	1.9	2.4
CV (%)	4.6	9.4	8.3	5.9	7.0

also showed that there is lower variability in seasonal summer ETo values in all zones. A steady trend in the value of seasonal summer ETo was found from 2014 to 2016 in all zones.

Table 2.12 indicates that there are increasing trends in the value of seasonal summer ETo in zones 2, 3, 4, and 5, compared to zone 1. The table also showed that in zone 2, percentage of increase in ETo values was the highest from 2008 to 2012, as a result of increase in maximum temperature (Table 2.3). The trend was different in the rest of the zones, where the percentage of increases were variables between the studied years.

The above results indicated that the spatial variability in ETo (annual, winter, and summer) was the lowest in zone 1 and the highest in zone 5. Furthermore, the highest temporal variability in ETo (annual, winter, and summer) existed in zone 2.

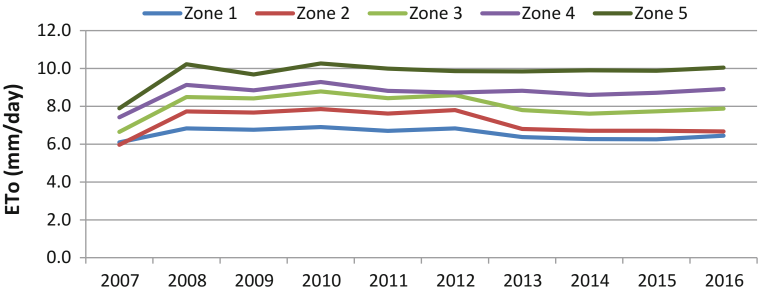


Fig. 2.9 Comparison between summer seasonal values of ETo in the five agro-climatic zones of Egypt

Table 2.12 Percentage of increase in summer seasons ETo values between zone 1 and the rest of the agro-climatic zones of Egypt

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
2007	–	2	9	22	30
2008	–	13	24	34	50
2009	–	13	24	31	43
2010	–	14	27	34	49
2011	–	14	26	32	49
2012	–	14	26	28	44
2013	–	7	22	38	54
2014	–	7	21	37	58
2015	–	7	24	39	58
2016	–	3	22	38	56

Coefficient of Determination Between Weather Elements and ETo

Table 2.13 presents the values of coefficient of determination (R^2) between ETo and the studied weather elements. The results in the table indicated that the highest value of coefficient of determination (R^2) between solar radiation and ETo was found in zone 3. The lowest value of R^2 was found in zone 5, where the highest value of solar radiation existed in this zone (Table 2.13).

With respect to maximum temperature, the highest value of R^2 was found in zone 2, the lowest value was found in zone 4. Furthermore, in zone 2, R^2 between maximum temperature and annual ETo value was equal to its counterpart value of summer value of ETo (Table 2.13). Table 2.3 shows that, in zone 2, maximum temperature was higher from 2008 to 2012 than the rest of the studied years, in addition, zone 2 have the highest value of the range.

Table 2.13 also reveals that the value of R^2 between minimum temperature and ETo values was the highest in zone 3 and the lowest value was found in zones 2 and 4. In addition, R^2 between minimum temperature and summer ETo value was the

Table 2.13 Value of R2 between weather elements and ETo (annual, winter, and summer) in the agro-climatic zones of Egypt

		SRAD	TMAX	TMIN	WIND	TDEW
Zone 1	Annual	0.54	0.83	0.68	0.07	0.05
	Winter	0.43	0.62	0.41	0.12	0.06
	Summer	0.53	0.86	0.85	0.14	0.19
Zone 2	Annual	0.50	0.95	0.60	0.26	0.15
	Winter	0.48	0.79	0.43	0.12	0.22
	Summer	0.47	0.95	0.65	0.33	0.11
Zone 3	Annual	0.82	0.93	0.76	0.60	0.03
	Winter	0.66	0.77	0.52	0.43	0.05
	Summer	0.79	0.86	0.78	0.60	0.07
Zone 4	Annual	0.59	0.56	0.60	0.49	0.42
	Winter	0.53	0.61	0.58	0.34	0.29
	Summer	0.60	0.49	0.58	0.57	0.48
Zone 5	Annual	0.14	0.82	0.63	0.52	0.71
	Winter	0.17	0.96	0.83	0.25	0.65
	Summer	0.13	0.73	0.53	0.62	0.69

highest than its counterpart of annual value in zones 2 and 3. Table 2.4 indicates that, in zone 4, the lowest values of minimum temperature existed.

Table 2.13 also indicates that lowest value of R^2 between each of wind speed and dew point temperature was found in zone 1. Our results in Table 2.5 and 2.6 showed that the highest value of these two weather elements existed in zone 1. Whereas the highest value of R^2 between dew point temperature and ETo was found in zone 5, where zone 5 has the lowest dew point temperature. Furthermore, in zones 1 and 5, R^2 between each of wind speed and dew point temperature and summer value of ETo was higher than its counterpart of annual ETo value.

Deviation from the Mean Value of Seasonal ETo

1. **The first agro-climatic zone**

Deviation from the mean value of seasonal ETo values of winter and summer in the first agro-climatic zone is presented in Fig. 2.10a, b. The figures showed that positive deviation (above the value of the mean) for winter ETo values was observed starting from 2008 to 2010. It became negative (below the value of the mean) in 2011, then turned positive in 2012 then turned to negative again and continued in 2016 (Fig. 2.10a). In the summer ETo, positive deviation was observed from 2008 to 2012 and then the deviation turned negative until 2016 (Fig. 2.10b).

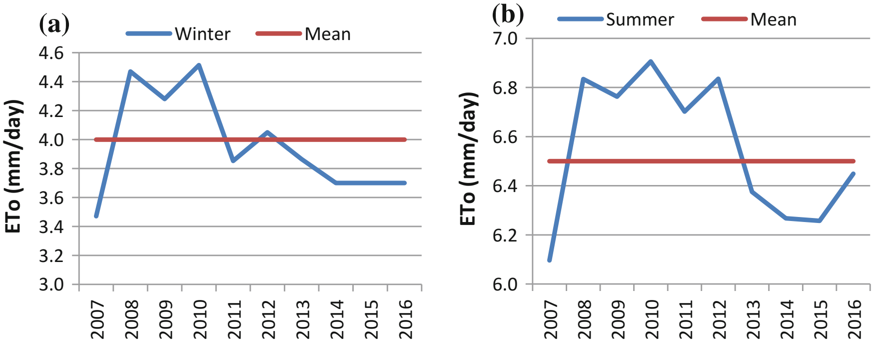


Fig. 10 Deviation of the ETo values from the mean **a** winter seasons ETo and **b** summer seasons ETo in the first agro-climatic zone

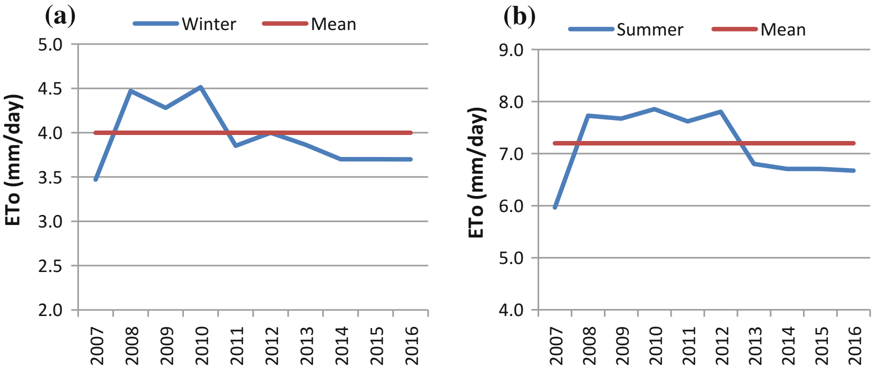


Fig. 2.11 Deviation of the ETo values from the mean **a** winter seasons ETo and **b** summer seasons ETo in the second agro-climatic zone

2. The second agro-climatic zone

Figure 2.11a shows that the negative deviations from the mean for winter values of ETo started from 2012 and continued to 2016. Negative deviations from the mean for the summer values of ETo started from 2013 and continued to 2016 (Fig. 2.11b).

3. The third agro-climatic zone

Similar to the trend observed in the second agro-climatic zone, Fig. 2.12a shows a negative deviations from the mean for winter values of ETo started from 2012 and continued to 2016. Negative deviations from the mean for the summer values of ETo started from 2013 and continued to 2016 (Fig. 2.12b).

4. The fourth agro-climatic zone

Figure 2.13a shows that, in the fourth agro-climatic zone, the negative deviations from the mean for winter values of ETo started from 2013 and continued to 2016.

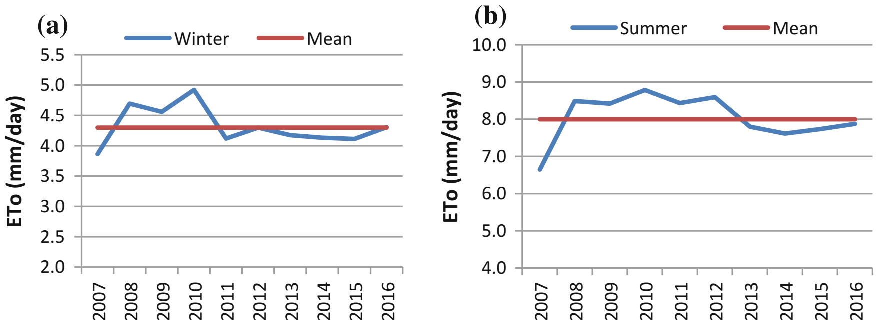


Fig. 2.12 Deviation of the ETo values from the mean **a** winter seasons ETo and **b** summer seasons ETo in the third agro-climatic zone

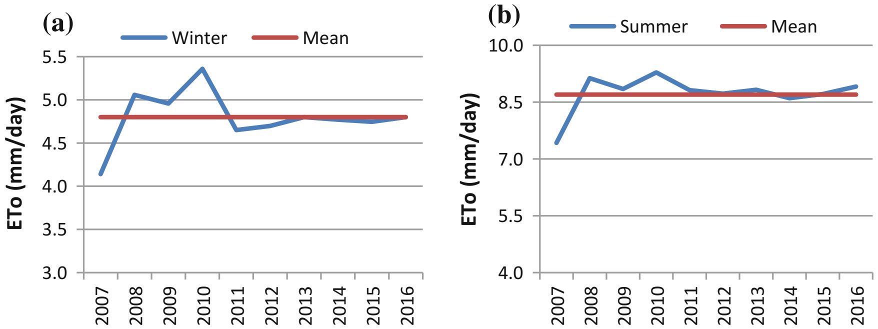


Fig. 2.13 Deviation of the ETo values from the mean **a** winter seasons ETo and **b** summer seasons ETo in the fourth agro-climatic zone

Negative deviations from the mean for the summer values of ETo started from 2014 and continued to 2015 and then became positive in 2016 (Fig. 2.13b).

5. **The fifth agro-climatic zone**

In the fourth agro-climatic zone, Fig. 2.14a, b shows negative deviations from the mean for both winter and summer values of ETo started from 2013 and continued to 2015 and then became positive in 2016.

Appropriate Values of ETo Time-Interval to Schedule Irrigation

According to the previous results in section, the appropriate interval of winter ETo values is different between the agro-climatic zones. Table 2.14 shows that the mean values of seasonal winter ETo over a certain number of years differed from one zone

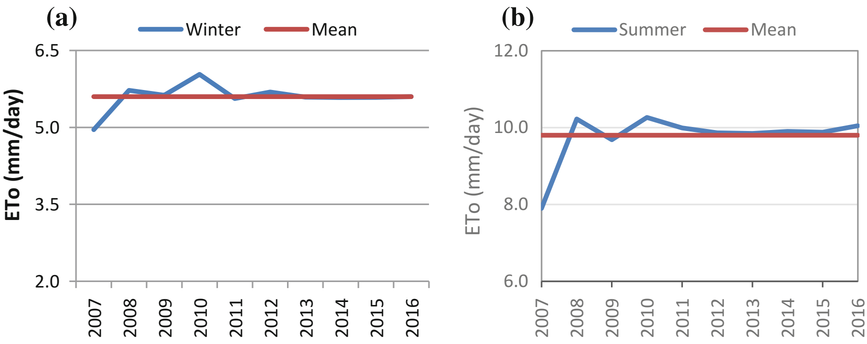


Fig. 2.14 Deviation of the ETo values from the mean **a** winter seasons ETo and **b** summer seasons ETo in the fifth agro-climatic zone

Table 2.14 Appropriate values of seasonal winter ETo to schedule irrigation in the five agro-climatic zones

	Zone 1 (2013–2016)	Zone 2 (2012–2016)	Zone 3 (2012–2016)	Zone 4 (2013–2016)	Zone 5 (2013–2016)
Nov	3.5	3.7	3.8	4.2	5.1
Dec	2.7	2.8	2.9	3.2	4.0
Jan	2.7	2.7	3.0	3.2	3.9
Feb	3.3	3.4	3.7	4.4	5.3
Mar	4.3	4.5	5.3	6.0	6.9
Apr	5.3	5.7	6.5	7.5	8.5
Mean	3.6	3.8	4.2	4.8	5.6

to another. In the first, the fourth and the fifth agro-climatic zones, the interval of four years from 2013 to 2016 is the proper interval to be used in irrigation scheduling for winter crops. Regarding the second and the third agro-climatic zones, the interval between the years of 2012–2016 is the suitable interval to schedule irrigation.

Similarly, Table 2.15 presents the mean values of summer ETo over a certain number of years. For summer crops, the first, the second, the third, and the fourth agro-climatic zones are the suitable interval between 2013 and 2016. For the fourth agro-climatic zone, the interval from 2014 to 2016 is the suitable interval.

Water Requirements for the Prevailing Crop Rotations

Crop rotation in Egypt was usually implemented in three years. In each year, the cultivated area was composed of three hectares. Each hectare is divided into three parts, and each part is cultivated with winter and summer crops. In this case, the rotation is more productive, sustainable and reduces pests and weeds.

Wheat, maize, and clover are the main crops in all the agro-climatic zones. Moreover, sugar beet in cultivated in the first to the fourth agro-climatic zone. Rice is only cultivated in the Nile Delta, represented by first and second agro-climatic zones. Sugarcane is only cultivated in Upper Egypt, represented by the fourth and fifth agro-climatic zones.

The Prevailing Crop Rotation in the First Agro-climatic Zone

Figure 2.15 presents the prevailing crop rotation in the first agro-climatic zone, as well as planting and harvest date for each crop.

The date of the Kc growth stages of the cultivated crops in the prevailing crop rotation and its values is presented in Table 2.16.

Using the value of ETo presented in Tables 2.14 and 2.15, as well as the values of Kc presented in Table 2.16, the values of water requirements for the crops cultivated in the prevailing crop rotation were calculated. The results in Table 2.17 showed that the values of water requirements of the cultivated crops in the prevailing crop rotation calculated using 2016 weather data was higher than its counterpart values calculated using ETo time-interval. Thus, 38 mm of irrigation water per the area of the crop rotation, which is three hectares can be saved, which is lower by 1% than the required irrigation water using 2016 weather data.

Table 2.15 Appropriate values of seasonal summer ETo to schedule irrigation in the five agro-climatic zones

	Zone 1 (2013–2016)	Zone 2 (2013–2016)	Zone 3 (2013–2016)	Zone 4 (2014–2016)	Zone 5 (2013–2016)
May	6.3	6.8	8.3	9.0	10.1
Jun	7.1	7.6	9.1	10.0	11.2
Jul	7.1	7.7	9.0	9.9	11.0
Aug	6.8	7.3	8.5	9.5	10.7
Sep	6.0	6.3	7.3	8.1	9.4
Oct	4.7	4.9	5.4	6.1	7.1
Mean	6.3	6.8	7.9	8.8	9.9

Year 1	Year 2	Year 3
Wheat (15 Nov-18 Apr) Peanut (5 May-25 Aug)	Clover (2 cuts) Cotton	Sugar beet Maize
Clover (2 cuts) (15 Oct-1 Feb) Cotton (15 Mar- Sep)	Sugar beet Maize	Wheat Peanut
Sugar beet (15 Oct- 12 Apr) Maize (15 May-1Sep)	Wheat Peanut	Clover (2 cuts) Cotton

Fig. 2.15 Prevailing crop rotation in the first agro-climatic zone

Table 2.16 Date of Kc growth stages and its values for the crops in the first agro-climatic zone

Crop	Data of growth stages			Kc values		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Wheat	16-Dec	22-Jan	18-Apr	0.31	1.06	0.19
Peanut	4-Jun	30-Jun	25-Aug	0.24	1.11	0.39
Clover (2 cuts)	26-Oct	3-Dec	1-Apr	0.26	1.13	0.40
Cotton	7-Apr	23-Jul	15-Aug	0.30	0.93	0.46
Sugar beet	11-Nov	4-Jan	12-Apr	0.27	1.15	0.95
Maize	6-Jun	3-Jul	1-Sep	0.24	1.04	0.58

Table 2.17 Water requirements for the prevailing crop rotation using 2016 weather data and ETo time-interval in the first agro-climatic zone

Crop	Water requirements (mm) under		Amount of saved water (mm)
	Irrigation scheduling using 2016 data	Irrigation scheduling using ETo time-interval	
Wheat	383	378	5
Peanut	565	559	6
Clover (2 cuts)	220	217	3
Cotton	877	867	10
Sugar beet	556	550	6
Maize	550	542	8
Total	3151	3113	38
Saving (%)	1		

The Prevailing Crop Rotation in the Second Agro-climatic Zone

The prevailing crop rotation in the second agro-climatic zone is presented in Fig. 2.16. The planting and harvest dates of the included crops in this rotation are included in Fig. 2.16.

Year 1	Year 2	Year 3
Sugar beet (15 Oct-12 Apr) Rice (15 May-16 Sep)	Wheat Soybean	Clover Maize
Wheat (15 Nov-18 Apr) Soybean (15 May- 25 Aug)	Clover Maize	Sugar beet Rice
Clover (15 Oct-15 Apr) Maize (15 May-1 Sep)	Sugar beet Rice	Wheat Soybean

Fig. 2.16 Pevailing crop rotation in the second agro-climatic zone

Table 2.18 Date of Kc growth stages and its values for the crops in the second agro-climatic zone

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Sugar beet	11-Nov	4-Jan	12-Apr	0.26	1.15	0.95
Rice	14-Jun	30-Jun	16-Sep	0.35	1.02	0.78
Wheat	16-Dec	22-Jan	18-Apr	0.31	1.08	0.19
Soybean	4-Jun	30-Jun	25-Aug	0.23	1.11	0.39
Clover	26-Oct	3-Dec	1-Apr	0.26	1.15	0.40
Maize	6-Jun	3-Jul	1-Sep	0.23	1.04	0.58

Table 2.19 Water requirements for the prevailing crop rotation using 2016 weather data and ETo time-interval in the second agro-climatic zone

Crop	Water requirements (mm)		Amount of saved water (mm)
	Irrigation scheduling using 2016 data	Irrigation scheduling using ETo time-interval	
Sugar beet	600	588	12
Rice	712	688	24
Wheat	399	390	9
Soybean	582	569	13
Clover	658	648	10
Maize	590	581	9
Total	3541	3464	77
Saving (%)	2		

Additionally, the date of each Kc growth stage and its value for the cultivated crops is presented in Table 2.18.

The results in Table 2.19 revealed that saving in the applied irrigation water to the crop rotation by 2% could occur if irrigation scheduling using ETo time-interval was used, compared to the required irrigation water to be applied when 2016 weather data. An amount of 77 mm could be saved per 3 ha, which is the area of the crop rotation.

The Prevailing Crop Rotation in the Third Agro-climatic Zone

In the third agro-climatic zone, the prevailing crop rotation is presented in Fig. 2.17, as well as planting and harvest dates of the cultivated crops.

Table 2.20 presents the date and the value of each Kc growth stage for the crops in the prevailing crop rotation in the third agro-climatic zone.

Year 1	Year 2	Year 3
Wheat (15 Nov-18 Apr) Soybean (15 May-25 Aug)	Faba bean Maize	Sugar beet Tomato
Faba bean (25 Oct-25 Apr) Maize (15 May-1 Sep)	Sugar beet Tomato	Wheat Soybean
Sugar beet (15 Oct-12 Apr) Tomato (1 May-1 Sep)	Wheat Soybean	Faba bean Maize

Fig. 2.17 Prevailing crop rotation in the third agro-climatic zone

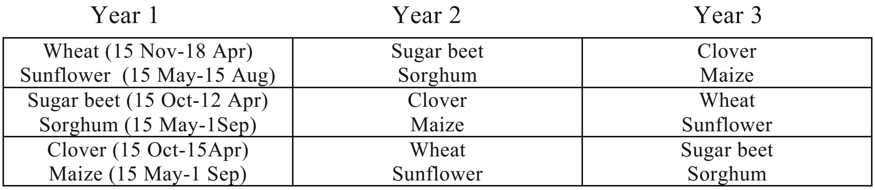
Table 2.20 Date of Kc growth stages and its values for the crops in the third agro-climatic zone

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Wheat	16-Dec	22-Jan	18-Apr	0.31	1.08	0.17
Soybean	4-Jun	30-Jun	25-Aug	0.21	1.11	0.39
Faba bean	29-Nov	24-Dec	25-Apr	0.27	0.99	0.19
Maize	6-Jun	3-Jul	1-Sep	0.21	1.03	0.58
Sugar beet	11-Nov	4-Jan	12-Apr	0.25	1.15	0.95
Tomato	1-Jun	2-Jul	1-Sep	0.21	1.10	0.65

Table 2.21 Water requirements for the prevailing crop rotation using 2016 weather data and ETo time-interval in the third agro-climatic zone

Crop	Water requirements (mm)		Amount of saved water (mm)
	Irrigation scheduling using 2016 data	Irrigation scheduling using ETo time-interval	
Wheat	448	434	14
Soybean	592	572	20
Faba bean	375	367	8
Maize	597	585	12
Sugar beet	647	630	17
Tomato	679	666	13
Total	3338	3254	84
Saving (%)	3		

Using ETo time-interval in irrigation scheduling of the cultivated crops in the third agro-climatic zone can result 84 mm saving in the applied water for the area of the crop rotation, which amounted to 3% of the required irrigation water to be applied when 2016 weather data was used (Table 2.21).



Year 1	Year 2	Year 3
Wheat (15 Nov-18 Apr) Sunflower (15 May-15 Aug)	Sugar beet Sorghum	Clover Maize
Sugar beet (15 Oct-12 Apr) Sorghum (15 May-1Sep)	Clover Maize	Wheat Sunflower
Clover (15 Oct-15Apr) Maize (15 May-1 Sep)	Wheat Sunflower	Sugar beet Sorghum

Fig. 2.18 Prevailing crop rotation in the fourth agro-climatic zone

Table 2.22 Date of Kc growth stages and its values for the crops in the fourth agro-climatic zone

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Wheat	17-Dec	23-Jan	18-Apr	0.29	1.08	0.17
Sunflower	3-Jun	26-Jun	15-Aug	0.20	1.09	0.37
Sugar beet	12-Nov	5-Jan	12-Apr	0.23	1.15	0.95
Sorghum	2-Jun	1-Jul	1-Sep	0.16	1.06	0.50
Clover	27-Oct	4-Dec	1-Apr	0.26	1.15	0.40
Maize	7-Jun	4-Jul	1-Sep	0.19	1.03	0.58

The Prevailing Crop Rotation in the Fourth Agro-climatic Zone

The prevailing crop rotation in the fourth agro-climatic zone is presented in Fig. 2.18. The figure also showed the planting and harvest dates of the cultivated crops.

Table 2.22 presents the date of each Kc growth stage, as well as its value for the cultivated crops in the fourth agro-climatic zone.

Table 2.23 shows that the amount of saved water can reach 72 mm per the area of the crop rotation, if irrigation scheduling was done using ETo time-interval. This amount of saved irrigation water represents 2% of the applied irrigation water using 2016 weather data.

The Prevailing Crop Rotation in the Fifth Agro-climatic Zone

In the fifth agro-climatic zone, the prevailing crop rotation is presented in Fig. 2.19, as well as planting and harvest dates of the cultivated crops.

The date of each Kc growth stage and its value for the cultivated crops in the fifth agro-climatic zone is presented in Table 2.24.

Table 2.23 Water requirements for the prevailing crop rotation using 2016 weather data and ETo time-interval in the fourth agro-climatic zone

Crop	Water requirements (mm)		Amount of saved water (mm)
	Irrigation scheduling using 2016 data	Irrigation scheduling using ETo time-interval	
Wheat	499	487	12
Sunflower	725	711	14
Sugar beet	743	733	10
Sorghum	725	710	15
Clover	756	745	11
Maize	643	633	10
Total	4090	4019	72
Saving (%)	2		

Year 1	Year 2	Year 3
Wheat (15 Nov-18 Apr) Sesame (5 May- 25 Aug)	Clover Maize	Faba bean Sorghum
Clover (15 Oct-15 Apr) Maize (15 May-1 Sep)	Faba bean Sorghum	Wheat Sesame
Faba bean (25 Oct-25 Apr) Sorghum (15 May-1 Sep)	Wheat Sesame	Clover Maize

Fig. 2.19 Prevailing crop rotation in the fifth agro-climatic zone

Table 2.24 Date of Kc growth stages and its values for the crops in the fourth agro-climatic zone

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Wheat	17-Dec	23-Jan	18-Apr	0.26	1.08	0.16
Sesame	5-Jun	1-Jul	25-Aug	0.18	1.11	0.39
Clover	27-Oct	4-Dec	1-Apr	0.21	1.15	0.40
Maize	7-Jun	4-Jul	1-Sep	0.18	1.03	0.58
Faba bean	30-Nov	25-Dec	25-Apr	0.23	0.99	0.17
Sorghum	2-Jun	1-Jul	1-Sep	0.15	1.06	0.50

The results in Table 2.25 clearly showed that, in the fifth agro-climatic zone, irrigation water saving can occur as a result of using irrigation scheduling depend on ETo time-interval, compared to implementing irrigation scheduling using 2016 weather data. The saved amount was 75 mm per three hectares, which represent 2% of the required water using 2016 data.

Table 2.25 Water requirements for the prevailing crop rotation using 2016 weather data and ETo time-interval in the fifth agro-climatic zone

Crop	Water requirements (mm)		Amount of saved water (mm)
	Irrigation scheduling using 2016 data	Irrigation scheduling using ETo time-interval	
Wheat	509	499	10
Sesame	799	788	11
Clover	804	790	14
Maize	685	667	18
Faba bean	510	502	8
Sorghum	799	785	14
Total	4106	4031	75
Saving (%)	2		

Conclusion

This chapter described the weather of the five agro-climatic zones of Egypt from agriculture point of view concerning ETo values (annual, winter, and summer). Our results indicated there were increasing trend in the past few years in all weather elements, except for solar radiation in the five agro-climatic zones. Solar radiation took a decreasing trend in the past few years.

Our results indicated that higher spatial variability between zone 1 and zone 5 expressed by higher CV% value of solar radiation and lower CV% value of maximum temperature, as well as higher values of minimum, minimum and dew temperatures, and wind speed were found. Furthermore, temporal variability within zone 1 expressed by higher CV% value of solar radiation and lower CV% value of maximum temperature, as well as higher values of minimum, minimum and dew temperatures, and wind speed, compared to in zone 5 were found.

Our results stated that the spatial variability in ETo (annual, winter, and summer) was the lowest in zone 1 and the highest in zone 5. Furthermore, the highest temporal variability in ETo (annual, winter, and summer) existed in zone 2.

Our results also revealed that the highest value of R^2 between weather elements and ETo values (annual, winter, and summer) was found between maximum temperature and ETo values in all zones, except zone 4, where the highest value was found between minimum temperature and ETo values. Whereas the lowest value of R^2 was found between dew point temperature and ETo values in all zones except zone 5, where the lowest value was found between wind speed and ETo values.

Furthermore, the deviation of ETo values (winter and summer) from its mean value was the highest in the first agro-climatic zone. It was with medium degree in the second and third agro-climatic zones. Whereas it was low in the fourth agro-climatic zone and it was very low in the fifth agro-climatic zone.

The analysis revealed that in the first agro-climatic zone, the interval between 2013 and 2016 is suitable to be used to schedule irrigation for both winter and summer crops. In the second and third agro-climatic zones, the interval between 2012 and 2016 is suitable for winter crops and the interval between 2013 and 2016 is suitable for summer crops. For the fourth agro-climatic zone, the interval between 2013 and 2016 is suitable for winter between 2014 and 2016 is suitable for summer crops. Whereas, in the fifth agro-climatic zone, interval between 2013 and 2016 is suitable for winter crops and summer crops.

Irrigation scheduling using ETo time-interval in calculating water requirements for the prevailing crop rotation in each agro-climatic zone resulted in water saving amounted to 38–84 mm for the area of the crop rotation in the five agro-climatic zones of Egypt. These saved amounts represent 1–3% of the required irrigation water to be applied when 2016 weather data was used to schedule irrigation.

The above results implied the suitability of the developed ETo intervals to be used in irrigation scheduling for the suggested crops to improve irrigation water management on the field level. It can rationalize the use of irrigation water in agriculture and reduced unnecessary losses. Our results can help policy makers in their future plan to manage water resources more sustainably and enhance current situation of water deficiency.

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Chapter 3
Crop Rotation Increases Land Productivity

Introduction

Population growth is a critical challenge facing governments around the world to supply the required amount of food to the public. In accordance to the United Nations' agenda for 2030 for sustainable development, namely the second goal: "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (United Nations 2015), increasing food security is a challenge in most of the developing countries with overpopulation problem like Egypt. Agriculture presents the supply side, where it provides food and population represents the demand side for agricultural commodities (USAID 2006).

Sustainable crop intensification entails increasing the number of crops grown per year on the same land, thereby raising yield per unit of area and time (Krupnik et al. 2015). Sustainable intensification aims to augment land productivity by increasing resource use efficiency and, at the same time, minimizing environmental destructions (Pretty and Bharucha 2014). Crop rotation plays an important role in increasing number of cultivated crops per year and, in the meantime, provides sustainable use of natural resources. Diverse crop rotations provide a yield-enhancing "rotation effect" compared to less diverse rotations (Berzsenyi et al. 2000). Monoculture cultivation often results in yield decreases (Peterson and Varvel 1989). Long-term studies have shown that crop rotations with or without legumes are essential to maintain high production levels (Mitchell et al. 1991). Furthermore, diversifying cropping systems with annual pulse crops, such as dry pea, lentil, and chickpea, could increase the systems' productivity, while decreasing the environmental impact (Gan et al. 2015).

Additionally, cultivation of three crops per year can be implemented within a crop rotation to improve soil fertility, when legume crop planted between two cereal crops. Sheha et al. (2014) indicated that cultivation of fahl clover (short season clover cultivar) after rice and before wheat resulted in an increase in wheat yield and reduced nitrogen depletion from the soil. Hamd-Alla et al. (2014) and Zohry et al. (2017)

S. Ouda et al., *Crop Rotation*, https://doi.org/10.1007/978-3-030-05351-2_3

indicated that wheat yield was increased by 10–15%, when fahl clover was planted between maize and wheat.

In this chapter, we tackled different concepts related to the increase in land productivity, as a result of implementing crop rotation. In addition, we reviewed the effect of several crop rotations implemented in Egypt on increasing land productivity under rain-fed and irrigation conditions in Egypt.

Monoculture Versus Rotation

Crop rotation plays an important role in increasing crops production, as well as increasing lands productivity. Crops' arrangement in the crop rotation allows sustainable use of light and nutrients. Corn and soybean grown in rotation typically out-yielded their monoculture counterparts, and the yield of corn typically is greater when grown in rotation with wheat or alfalfa, compared to wheat grown in monoculture (Stanger and Lauer 2008). Gan et al. (2015) reported that, in three-year wheat crop sequence study, repeated for five cycles from 2005 to 2011, pulse-based system increased total grain production by 36%, improved protein yield by 51%, and enhanced fertilizer-N use efficiency by 33%, over the summer fallow system. Angus et al. (2015) indicated that wheat yield varied with species of break crop, ranging from 0.5 ton/ha after oats to 1.2 ton/ha after grain legumes, compared to wheat continuous cultivation. Smith et al. (2017) reported that crop production in the semiarid Northern Great Plains has historically been limited to wheat cultivation, with fallow every second or third year. The use of an annual legume green manure to partially replace fallow and a continuous diversified rotation of cereal–oilseed–cereal–pulse crops, wheat–canola–wheat–dry pea rotations were more profitable than the traditional wheat systems.

Raised Beds Versus Basin Cultivation

Basin cultivation is a common practice for farmers around the world. This practice is characterized by the application of higher irrigation water, which results in increasing runoff and deep percolation. On the other hand, cultivation on raised beds proved to reduce the applied water to crops, increase the final yield, and improve rhizosphere environment. Abouelenein et al. (2009) indicated that 20% of the applied water to wheat was saved under raised beds cultivation. It was also reported that cultivation on raised beds increased productivity by 15%, as a result of an increase in radiation used efficiency because crops are more exposed to solar radiation (Abouelenein et al. 2010). Furthermore, it increases nitrogen use efficiency and increases water use efficiency (Karrou et al. 2012; Majeed et al. 2015). Ahmad et al. (2009) reported that raised beds cultivation increased water use efficiency, where 20–25% of irrigation water was saved. It also provided better opportunities to leach salts from the beds

(Bakker et al. 2010), thus improving productivity. Hobbs et al. (2000) demonstrated that raised beds planting significantly contributed to improving water distribution and efficiency, increased fertilizer use efficiency, and reduced weed infestation, lodging and seed rate without sacrificing yield. Furthermore, Majeed et al. (2015) indicated that raised beds planting of wheat, not only saved water but also improved fertilizer use efficiency and increase grain yield by 15%, compared to flat planting.

Other studies on raised beds cultivation showed that it reduces seed mortality rates and improves soil quality (Limon-Ortega et al. 2002), which led to enhanced root growth, and gave higher yield (Dey et al. 2015). Root length density was also longer in upper 45 cm in beds due to porous soil environment (Dey et al. 2015). Raised beds cultivation significantly and substantially increased maize growth, microbial functional groups, and enzyme activities, compared to flat planting; thus it increases the availability of essential crop nutrients by stimulating microbial activity (Zhang et al. 2012).

Sing et al. (2010) found lower water consumption and higher wheat yield under raised beds planting than under conventional flat beds planting due to decrease in irrigation amount. Raised beds planting also created better soil physical environment throughout the crop growth period, which led to higher crop productivity (Aggarwal and Goswami 2003). Research trials in India showed that raised beds were most suited for growing crops like maize, wheat, and soybean, as it significantly decreased water use (Zhang et al. 2007).

Thus, cultivation on raised bed could contribute to increasing land productivity, when implemented for the cultivated crops in the crop rotation. It could increase crops productivity through improve growth environments for the growing plants.

Monoculture Versus Intercropping

Intercropping systems are one dimension that can attain sustainable crop intensification. Intercropping and multiplicity of crop sequence are considered successful avenues to increase the cropped area without altering the area cultivated by the main crops in winter or summer (Kamel et al. 2010). Intercropping is a planting system which involves cultivation of two crops (main and secondary crops) resulted in increasing light interception, root contact with more soil, microbial activity and deterrent to pests and weeds (Altieri 1999). Furthermore, the most common reason for the adoption of intercropping systems is yield advantage, which is explained by the greater resource depletion by intercrops than monocultures (Hauggaard-Nielsen et al. 2006). Thus, intercropping increases unit land productivity (harvest two types of crops from the same area), increases water productivity (using amount of irrigation water applied to one crop to irrigate two crops), and increases farmer's income (reduce risks from crop failure) (Anderson 2007). The efficiency of the intercropping is directly depended on proper management of the factors of production, such as the spatial arrangement of crops and planting density to reduce the competition for resources and increase the efficiency of the system (Porto et al. 2011). These factors, when properly managed, can bring ecological and economic benefits to the activity as a result of increasing production when compared to monoculture (Batista et al. 2016). Furthermore, intercropping with legumes can be an excellent practice for controlling soil erosion and sustaining crop production (Dwivedi et al. 2015). Deep roots of legume crops penetrate far into the soil and use moisture and nutrients from deeper soil layers, whereas shallow roots of cereal crops fix the soil at the surface and thereby help to reduce erosion (Machado 2009). Growing legumes with cereals results in N2 fixation in the soil, and consequently, organic content increases (Hauggaard-Nielsen et al. 2006).

Reduced runoff and soil loss were observed in intercrops. Sorghum intercropped with cowpea system reduced runoff by 20–30% compared to sorghum sole planting and by 45–55% compared to cowpea monoculture. Additionally, soil loss was reduced with intercropping by more than 50%, compared with sorghum and cowpea monocultures (Lithourgidis 2011). Some legume crops are better in maintaining crop cover than the others. Kariaga (2004) compared between cowpea intercropped with maize system and bean intercropped with maize system regarding soil erosion and found that cowpea performed, as the best cover crop, compared to bean in reducing soil erosion.

To increase the advantage of using intercropping, cultivation on raised beds is essential. Cultivation on raised beds can reduce crop lodging (Wang et al. 2009), where it exerts control on the applied water resulting in less water and nutrient loss through deep percolation, thus reducing total water requirements for crops (Dogan and Kirnak 2010).

Cultivation of Three Crops Per Year

Another innovation can be done to increase land productivity under crop rotation is to change crop sequence from two crops per year (winter then summer crop) to three crops per year (winter, fall then summer crop) or (winter, early summer then late summer crop). The major benefits resulted from the use of this practice is to increase land productivity, improve, and sustain soil fertility and increase farmers' income (Sheha et al. 2014). Cultivation of three crops per year can integrate the advantages of well-developed eco-agricultural techniques (Kaixian and Bozhi 2014).

Zohry et al. (2017) compared between the effect of conventional crop sequence, namely wheat then maize with cultivation of three crops per year, namely maize, fahl clover, then wheat on wheat yield. Fahl clover is a variety of Egyptian clover, which has stem branching ability and is cut only once. Because fahl clover is characterized by rapid growth and large forage yield, it can be cultivated as early winter season starting in September and stays until the beginning of November, where its growing season is between 60 and 70 days (Bakheit et al. 2016).

Their results indicated that wheat productivity was increased by 16 and 47% in the first and second season, respectively, when fahl clover followed maize, compared to the conventional crop sequence. This result attributed to the residual effect of fahl clover cultivated before wheat on increasing available nitrogen, which benefited wheat yield more in the second growing season. Furthermore, soil quality can be improved by the inclusion of legumes in a cropping sequence (Espinoza et al. 2015). It also influences specific microorganism populations in the rhizosphere (McCallum et al. 2004) for the benefit of following crops. Zohry et al. (2017) also indicated that wheat water productivity in the three crops cultivated per year was increased by 46 and 63% in the first and second season, respectively, compared to its counterpart value in conventional crops sequence. This improvement could be attributed to improved porosity in the soil and soil structure as indicated by McCallum et al. (2004).

Sheha et al. (2014) reported that cultivation of fahl clover before sugar beet and after rice increased sugar beet yield as a result of nitrogen fixation, which accelerates the microbial activity of the soil. Pokhrel and Pokhrel (2013) indicated that considerable amount of residue after harvesting legume crops with narrower C/N ratio is left in the soil which upon decomposition improves the physical condition and fertility of soil.

A common practice by some farmers in Egypt, after early sugar beet or faba bean (cultivated in the end of September), soybean, or sunflower, can be cultivated as early summer crop, where sugar beet or faba bean is harvested in March. Soybean or sunflower can be cultivated in March and harvested in June, where another crop can be cultivated after it as a late summer crop (unpublished data).

Effect of the Duration of Crop Rotation on Land Productivity

The duration of a crop rotation has an effect on the productivity of the cultivated crops in it. In this context, Toaima (2007) studied the effect of crop rotation duration (every year, two-year and three-year rotations) on cotton yield. The results indicated that cotton yield was increased by 11 and 24% under the two-year and three-year rotations, respectively, compared to cotton cultivated every year. Similarly, Abou-Kersha (1998) indicated that three-year crop rotation resulted in an increase in cotton yield by 11%, compared to the cultivated cotton in the two-year rotation.

Furthermore, Abou-Kersha et al. (1998) examined the effect of crop rotation on maize and soybean in two-year and three-year rotation. Their results indicated that both maize and soybean were significantly affected by the length of the crop rotation. The yield of maize and soybean grown in three-year rotation was higher by 9 and 5%, compared to its counterpart values in two-year rotation.

A comparison between rice two-year crop rotation with its counterpart three-year crop rotation revealed that rice yield was increased by 29% under the three-year crop rotation, compared to the two-year crop rotation (Kamel et al. 2010).

Crop Rotations in Egypt

Crop rotation can be the solution of agricultural lands' fragmentation in Egypt, where it could be implemented as intensified crop sequences in assemblies consist of several farmers' lands. Furthermore, cultivation should be implemented on raised beds to save 20% of the applied water and fertilizer under surface irrigation, in addition to increase the yield by 10–15% (Abouelenein et al. 2010). The suggested crop rotation contained intercropping systems to increase intensification ratio through increasing the number of cultivated crops. Furthermore, farmer's income can increase under these rotations.

Crop rotation in Egypt is usually implemented in three years. In each year, the cultivated area is composed of 3 ha. Each hectare is divided into three parts and each part is cultivated with winter and summer crops. In this case, the rotation is more productive, sustainable and reduces pests and weeds. The prevailing rotation is usually cultivated using the traditional method, i.e., narrow furrows or flat cultivation, which results in high applied irrigation water and fertilizer.

Crop Rotations in the Rain-Fed Area in Egypt

In Egypt, there are two governorates' practice rain-fed agriculture, i.e., North Sinai in the north-east coast of Egypt and Marsa Matrouh on the north-west coast of Egypt. Barley and wheat, in addition to few fruit trees, are the main cultivated crops in these areas. Moisture stress, soil erosion, and nutrient depletion as a result of cereal mono-cropping are threats to agricultural sustainability in these areas. Furthermore, low yields per hectare are obtained in the rain-fed areas, which could be attributed to poor seeds quality, inadequate and imbalanced fertilizers, and poor crop management practices (Khalifa et al. 2004).

Implementing crop rotations, where legume crops followed cereals crops proved to increase productivity of cereal crops, as these cereal crops benefit from nitrogen fixed by legume and decomposition of roots and nodules (Shams and Kamel 2014). Previous research conducted by Khalifa et al. (2004) on comparing barley monoculture and barley grown in two-year crop rotation, and followed by pea or lentil, indicated that barley yield was significantly increased, compared to barley monoculture. Furthermore, the yield of barley grown after pea or lentil increased by 113 and 104%, respectively, compared to barley monoculture. These results implied that continuation of barley cultivation exhausted the soil and depleted nutrients from it. Furthermore, including legumes in the crop rotation is recommended for sustaining soil productivity and improving barley productivity under rain-fed conditions.

Shams and Kamel (2014) conducted monoculture rotation contained either barley or wheat and compared it with two-year rotation, where barley or wheat was rotated with lentil or pea. The results revealed that the yield of either barley or wheat was drastically decreased in monoculture, where barley and wheat yields were decreased by 34 and 28%, respectively, whereas barley and wheat yield reductions in the two-year rotation were lower, namely 13 and 9%, respectively, in the two-year rotation. Although the two cereal crops were rotated with the two legume crops, the reduction in the cereal crops was due to lower incidence of rain in the second year of the rotation.

In addition, three crop rotations were implemented in North Egypt under rain-fed condition to assess the effect of the preceding crop on barley yield. These three crop rotations were: barely/barely, lentil/barley, and pea/barley. The results indicated that an improvement in barely yield occurred when either pea or lentil preceded it (Abd El-Hadi et al. 2002).

Crop Rotations in the Agro-climatic Zones of Egypt

According to Ouda and Noreldin (2017), five agro-climatic zones are distinguished in Egypt. They used the evapotranspiration data (ETo) from 2005 to 2014 to develop these agro-climatic zones in the old land surrounding the Nile Delta and Valley (Fig. 3.1).

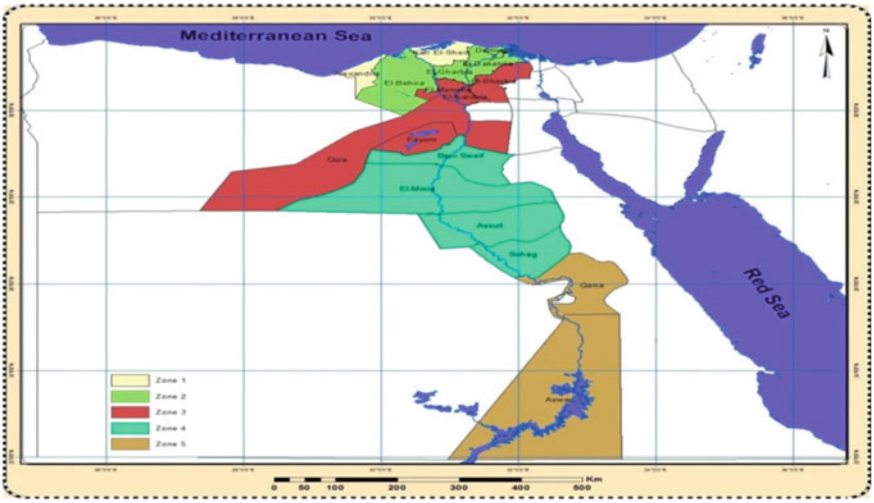

Fig. 3.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

Crop Rotation in the Fourth Agro-climatic Zone

Abou-Kersha (1998) studied the effect of cotton monoculture and two cotton intercropping systems (relay intercropped cotton on onion and relay intercropping cotton on faba bean) on cotton yield in two-year (Fig. 3.2) and three-year crop rotations (Fig. 3.3).

The first section of the two-year crop rotation (Fig. 3.2) contained the three systems with cotton, namely clover (on cut) then cotton, cotton relay intercropped on onion, and cotton relay intercropping on faba bean. In cotton relay intercropped on onion, onion seedling cultivated in November in four rows on the top of the raised beds and cotton is cultivated relay on onion in March on both sides of the raised beds. In this system, onion and cotton planting densities are 75 and 100% of its recommended density. Onion harvested in May and cotton continues to grow until September, where harvest occurs (Zohry 2005), whereas in cotton relay intercropping on faba bean, faba bean is cultivated in October in three rows on the top of the raised beds and cotton is cultivated relay on faba bean in March on both sides of the raised beds, with 100% of its planting density and continued to grow until September. Faba bean is harvested in April and cotton continues to grow until September, where harvest occurs. In both systems, cotton shares its first two irrigation events with the last two irrigations events of onion or faba bean (Zohry 2005).

Year 1	Year 2
Clover (on cut)/cotton relay intercropping cotton on onion relay intercropping cotton on faba bean	(Wheat + clover) Maize
(Wheat + clover) Maize	Clover (on cut)/cotton relay intercropping cotton on onion relay intercropping cotton on faba bean

Fig. 3.2 Two-year crop rotation for cotton implemented in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Clover (on cut)/cotton relay intercropping on onion relay intercropping cotton on faba bean	Clover then maize	Wheat then maize
Wheat then maize	Clover (on cut)/cotton relay intercropping on onion relay intercropping cotton on faba bean	Clover then maize
Clover then maize	Wheat then maize	Clover (on cut)/cotton relay intercropping on onion relay intercropping cotton on faba bean

Fig. 3.3 Three-year crop rotation for cotton implemented in the fourth agro-climatic zone

In the second section of the rotation, wheat and clover were cultivated as winter crop and maize was cultivated as a summer crop.

In the three-year crop rotation, the crops in the first section were similar to the crops in the first section of the two-year rotation. The second section of the rotation included wheat then maize, and the third section included clover then maize (Fig. 3.3).

The results revealed that, in the two-year crop rotation, cotton intercropped with faba bean gave higher yield, compared to cotton monoculture by 5%, whereas in the three-year rotation, cotton intercropped with faba bean was higher by 6%. In each cropping systems, the yield of clover, onion and faba bean yield were higher in the three-year crop rotations, compared to the two-year crop rotations.

Another crop rotation was implemented by Abou-Kersha et al. (1998) in the fourth agro-climatic zone to examine the effect of preceding crops in the rotation on maize and soybean yield under two-year and three-year rotations. In the two-year crop rotation, wheat and onion preceded maize and soybean in the first section of the rotation, whereas in the second section of the rotation, faba bean and clover preceded maize and soybean (Fig. 3.4).

In the three-year crop rotation, wheat preceded maize and soybean in the first section. Onion and faba bean preceded maize and soybean in the second section. Faba bean and clover preceded maize and soybean in the third section (Fig. 3.5).

Their results showed that the yield of maize and soybean was the highest after faba bean, followed by clover, followed by onion in both the two-year and three-year rotations. Maize yield was increased by 41 and 26% after faba bean and clover, respectively, compared to its cultivation after wheat. Soybean yield was increased by 36 and 22% after faba bean and clover, respectively, compared to its cultivation after wheat.

Year 1	Year 2
Wheat + onion Maize + soybean	Faba bean + clover Maize + soybean
Faba bean + clover Maize + soybean	Wheat + onion Maize + soybean

Fig. 3.4 Two-year crop rotation for maize and soybean in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Wheat Maize + soybean	Faba bean +clover Maize + soybean	Onion + faba bean Maize + soybean
Onion + faba bean Maize + soybean	Wheat Maize + soybean	Faba bean +clover Maize + soybean
Faba bean +clover Maize + soybean	Onion + faba bean Maize + soybean	Wheat Maize + soybean

Fig. 3.5 Three-year crop rotation for maize and soybean in the fourth agro-climatic zone

Similarly, Farghly and Zohry (2002) evaluated the effect of the preceding crop sequences on cotton yield in a three-year crop rotation repeated twice in the fourth agro-climatic zone. Four crop rotations were implemented, where in each rotation different crop sequences preceded cotton as follows: wheat/maize, wheat/soybean, faba bean/maize, and faba bean/soybean. The results indicated that cotton yield was 14% higher when faba bean/soybean were the preceding crops, compared to cereals (wheat/maize) preceded cotton.

Additionally, Abou-Keriasha et al. (2012) conducted two cycles of crop rotations, each for three years in the fourth agro-climatic zone on clay loamy soil to compare between the prevailing three-year rotation cultivated by the farmer in the surrounding area (Fig. 3.6) and two proposed intensive rotations (Figs. 3.7 and 3.8) with respect to increasing land productivity.

The prevailing crop rotation was characterized by cultivation of mono-crops in each growing season, in the three years and in the two cycles.

The two proposed crop rotations were implemented on raised beds. It was characterized by increasing of number cultivated crops, implementing intercropping systems and cultivation of three crops per year.

With respect to the first proposed crop rotation (Proposed I) (Fig. 3.7), in the first section, cotton is relay intercropped with onion (Zohry 2005). After the harvest of onion, sesame intercropped with cotton and replaced onion. In this system, sesame was cultivated on one row above the raised beds and continued to grow until September, where harvest occurs. Thus, the above intensive system started in November by the cultivation of onion and ended in September in the following year.

Year 1	Year 2	Year 3
Clover Cotton	Faba bean Maize	Wheat Maize
Wheat Maize	Clover Cotton	Faba bean Maize
Faba bean Maize	Wheat Maize	Clover Cotton

Fig. 3.6 Prevailing crop rotation in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Cotton relay intercropped on onion then sesame intercropped with cotton	Faba bean+clover Maize Fahl clover	Wheat Cowpea intercropped with maize
Wheat Cowpea intercropped with maize	Cotton relay intercropped on onion then sesame intercropped with cotton	Faba bean+clover Maize Fahl clover
Faba bean+clover Maize Fahl clover	Wheat Cowpea intercropped with maize	Cotton relay intercropped on onion then sesame intercropped with cotton

Fig. 3.7 First proposed rotation in the fourth agro-climatic zone (Proposed I)

Year 1	Year 2	Year 3
Cotton relay intercropped on wheat then cowpea intercropped with cotton	Faba bean intercropped with onion Cowpea intercropped with maize	Faba bean intercropped with wheat Soybean intercropped with maize Fahl clover
Faba bean intercropped with wheat Soybean intercropped with maize Fahl clover	Cotton relay intercropped on wheat then cowpea intercropped with cotton	Faba bean intercropped with onion Cowpea intercropped with maize
Faba bean intercropped with onion Cowpea intercropped with maize	Faba bean intercropped with wheat Soybean intercropped with maize Fahl clover	Cotton relay intercropped on wheat then cowpea intercropped with cotton

Fig. 3.8 Second proposed rotation in the fourth agro-climatic zone (Proposed II)

In the second section of “Proposed I” rotation (Fig. 3.7), wheat was cultivated in the winter and in the summer season, and cowpea was intercropped with maize. This system proved to increase maize yield and reduced associated weeds (Zohry 2005). Cowpea shared the applied irrigation water with maize under this system. Maize and cowpea planting density under this system are 100 and 50% of its recommended density. Maize productivity increases by 10% under this system and no reduction in cowpea productivity occurred (Hamd-Alla et al. 2014). Dahmardeh et al. (2010) stated that in intercropping legume with cereals, legumes fix atmospheric nitrogen, which may be utilized by the host plant or may be excreted from the nodules into the soil and be used by other plants growing nearby.

In the third section of “Proposed I” rotation (Fig. 3.7), two crops are cultivated in the winter, namely faba bean and clover, and maize as summer crop was cultivated. Fahl clover as early winter crop was then cultivated after maize.

Regarding the second crop rotation (Proposed II, Fig. 3.8), cotton relay intercropped on wheat and cowpea intercropped with cotton were implemented. In relay intercropped cotton on wheat, Zohry (2005) indicated that wheat is cultivated in four rows above the raised beds in November with 70% of its recommended planting density. Cotton is cultivated in March on both sides of the raised beds with 100% of its planting density. Wheat is harvested in April and cotton continues to grow until September where its harvest occurs. Thus, relay intercropping cotton on wheat system is characterized by three main phases. In the first phase, wheat plants are in its vegetative stage grown from November till March. In the second phase, intercropping of cotton with wheat. Cotton plants in its seedling stage grow from March till April and share this period with wheat plants in its reproductive stage. Whereas, in the third phase, sole cotton grow in it vegetative then reproductive stage from April till September (Zohry 2005). The two component crops in the system interact directly only during the second phase; however, the physiology, ecology, and productivity of the relay intercropping system are determined by the spatial architecture and temporal dynamics of the leaf canopy and the root systems during the whole growing cycle (Zhang et al. 2007). Furthermore, Zhang et al. (2008) stated that the N-uptake of cotton was diminished during the intercropping phase, but recovered partially during later growth stages, with low effect on final cotton yield. Furthermore, they also stated that intercrops used more nitrogen per unit production than mono-crops, which can reduce environmental risks of nitrogen leaching to ground water. After wheat harvest in April, cowpea is cultivated in two rows on the raised beds to replace wheat.

In the second section of the "Proposed II" rotation (Fig. 3.8), faba bean was intercropped with wheat in the winter season (Abdel-Wahab and El Manzlawy 2016). In this system, 100% of wheat recommended planting density is cultivated, where six rows above the raised beds are planted. Faba bean planting density under this system is 50% of its recommended density. Faba bean is planted on both sides of the raised beds. In the summer season, soybean was intercropped with maize. In this system, soybean is cultivated in the first of May on the top of the raised beds in two rows and maize is cultivated on both edges of the raised beds 21 days after soybean planting. Planting densities of soybean and maize were 50% of its recommended densities (Sherif and Gendy 2012). Additionally, fahl clover was cultivated as an early winter crop.

In the third section of "Proposed II" rotation (Fig. 3.8), faba bean was intercropped with onion in the winter season (Abou-Keriasha et al. 2013), where 75% of onion recommended planting density is cultivated, in four rows above the raised beds. Faba bean planting density was 50% of its recommended density planted on both sides of the raised beds. Furthermore, in the summer season, cowpea was intercropped with maize.

The results indicated that wheat yield was increased in both Proposed I and II crop rotations by 4 and 1%, compared to its counterpart value under the prevailing crop rotation. With respect to maize, its yield was increased by 3% in Proposed I rotation, compared to its counterpart value under the prevailing crop rotation. Cotton yield was also increased by 4% in Proposed I, and by 8% in Proposed II rotation, compared to its counterpart value under the prevailing crop rotation.

Intensification index, which represents the cropped area divided by land area multiplied by 100, was increased from 2.05% under the prevailing crop rotation to 2.50% under Proposed I rotation, and to 2.64% under Proposed II rotation, which implied high increase in land productivity.

Conclusion

Population growth is a critical challenge facing governments around the world to supply the required amount of food to the public. Implementing crop rotation, where legume crops rotating with cereal crops, results in increasing the yield of cereal crops. Cultivation on raised beds within a crop rotation can play a role in increasing land productivity, where it was proved that cultivation on raised beds increases crop yield by 15–20%. Similarly, implementing intercropping systems within a crop rotation proved to increase land productivity. Additionally, cultivation of three crops per year also contributes in increasing land productivity within a crop rotation. Reviewing the implemented crop rotations in Egypt within the past 20 years demonstrated these benefits. Thus, to increase food production in overpopulated countries, intensive crop rotations should be practice.

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Chapter 4
Crop Rotation Maintains Soil Sustainability

Introduction

Soil is increasingly recognized as a non-renewable resource on a human life scale because once degraded its regeneration is an extremely slow process (Lal 2015). It is an important asset that needs to be properly managed to achieve sustainability (Malik et al. 2014). Additionally, soils are the medium, in which nearly all food-producing plants grow (Camarsa et al. 2014). Because soil is a very complex system, it may be described as a multicomponent and multifunctional system (Kibblewhite et al. 2008). Soils are originated depending on several factors, such as parent material, climate, and topography, which largely determine the dominant physical and chemical properties of these soils. These properties are often altered by agricultural interventions such as drainage, irrigation, use of lime to alter soil reaction and additions of plant nutrients (Van-Camp et al. 2004).

Soil management is essential to all agricultural systems. It has an important influence on its microbial properties (García-Orenes et al. 2013). Unsuitable land management can lead to a loss of soil fertility and a reduction in the abundance and diversity of soil microorganisms (Caravaca et al. 2002). Different agricultural practices, such as land clearing and burning of crop residues, have led to a rapid decline in soil carbon reserves (Kirschbaum et al. 2008). Declines in soil organic contents were observed following the change from native vegetation or pasture to annual crops (Luo et al. 2010). Soil microbes modify soil structure by aggregating both mineral and organic constituents via production of extracellular compounds with adhesive properties. Such compounds are produced by bacteria and fungi as a feeding mechanism, to aid colony coalescence and as protective coatings against desiccation (Bhuyan et al. 2014). Soil carbon loss can be attributed to microbial respiration (Stockmann et al. 2013). Furthermore, recent studies suggested that carbon loss occurred through soil erosion and runoff (Chappell et al. 2015). In addition, leaching losses of dissolved organic carbon may also be an important pathway of carbon loss from agricultural systems (Kindler et al. 2010).

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The use of crop rotation can play an important role in improving soil management. Both soil physical and chemical properties can be improved by crop rotation. The appropriate choice of crops within the rotation and their sequence is crucial if nutrient cycling within the field system is to be optimized and losses minimized over the short and long term. Each crop species has slightly different characteristics, e.g., N demanding or N2 fixing (Mohler 2001), shallow or deep rooting (Machado 2009), as well as amount and quality of crop residue returned (Hauggaard-Nielsen et al. 2006). These characteristics along with existing biotic and abiotic factors determine the ultimate suitability of a break crop in a given cropping system (Malik 2010).

In this chapter, we reviewed the previous literature concerning the positive effects of implementing crop rotation instead of monoculture cultivation on soil physical, chemical, and biological characteristics. Furthermore, we reviewed previous research done on crop rotations implemented in Egypt to improve soil fertility.

Soil Physical Properties

Soil physical properties provide information related to water and air movement through soil, as well as conditions affecting germination, root growth, and erosion processes. Additionally, it forms the foundation of other chemical and biological processes, which may be further governed by climate, landscape position, and land use (French et al. 2009). Key soil physical indicators include soil structure, soil water, and bulk density (Wixon and Balser 2009).

Soil Structure

Soil structure is evaluated by soil aggregate stability and porosity. Soil aggregate stability involved in maintaining organic carbon accumulation, infiltration capacity, movement and storage of water (Shukla et al. 2003), and root and microbial community activity (Rimal and Lal 2009). Soil aggregate stability can also be used to measure soil resistance to erosion and management changes (Moebius et al. 2007). An enhanced aggregate stability decreases the losses of soil carbon, nitrogen, and phosphorus (Kasper et al. 2009). When soil aggregates break down, finer particles are produced and easily carried away by wind and water flow, which tend to clog soil pores, leading to the formation of soil crusts, reducing infiltration, enhances surface runoff and thus promotes further water erosion (Yan et al. 2008). Calcium carbonate and organic matter are soil properties most closely correlated with soil aggregate stability (Canasveras et al. 2010). Calcium carbonate contents influence soil aggregation through their cementing effects and preventing aggregate dispersion (Amezketa 1999).

Soil organic matter content can affect soil structure, as well as soil aggregate stability through the transient aggregating effect of polysaccharides on micro-aggregates, it could increase aggregate coherence against slaking due to hydrophobic materials, it could, temporarily, stabilizing effect of roots and hyphae on macro-aggregates, and it could, persistently affect of polymers and aromatic compounds on micro-aggregates (Calero et al. 2008). Soil aggregate stability depends on soil type, on the content of organic matter (Šimanský et al. 2013), on the biological activity of the soil (Oades 2005), on fertilization (Annabi et al. 2007), as well as on the form of soil disturbance, frequency of passage of machinery (Safadoust et al. 2006), and vegetation cover (Peregrina et al. 2010).

Deterioration in soil aggregates is often occurred by agricultural practices, such as tillage by directly breaking the soil particles or indirectly by the disruption of potential aggregate binding agents (Yuan-Ying and Liang-Dong 2007). Tillage has also been found to alter soil microbial community dynamics (Wang et al. 2010). An et al. (2010) concluded that different plant communities affect soil aggregate stability and the distribution of organic carbon and nitrogen, where it was quite low under bare fallow land and cropping land soils. They added that re-vegetation of eroded soils accelerates soil remediation and rehabilitation. Furthermore, soil organic matter is known to have a strong relationship with aggregate formation and stabilization (Six et al. 2002). Li et al. (2005) indicated that land use and soil cultivation can change the total amount of soil organic matter stabilized, but they may also change the relative importance of the processes that protect soil organic matter. Furthermore, inadequate soil management causes the breakdown of soil structure and consequently leads to soil compaction and compression of soil aggregates, resulting in reduced pore volume (Batey 2009).

Njaimwe et al. (2018) compared between the effect of conventional tillage and no-till under three crop rotations, namely maize–fallow–maize, maize–wheat–maize, and maize–oat–maize. The results indicated that no-till had inconsistent effects on soil organic contents relative to conventional tillage but resulted in improved soil stability index. The maize–oat–maize rotation enhanced soil organic contents relative to the maize–wheat–maize and maize–fallow–maize rotations. Across tillage practices, the maize–oat–maize rotation significantly increased the soil aggregate stability index compared to the maize–wheat–maize and maize–fallow–maize rotations. Generally, the results indicated that, in the short term, cover crops, especially oats, have greater influence on soil organic content accumulation and aggregate stability. Moreover, no-tillage system associated with crop rotation increases the amount of crop residues left as mulch on the topsoil and could be an important and sustainable alternative for soil management in tropical and subtropical conditions.

Soil aggregate stability is thought to be depended on a combination of plant roots and mycorrhizal fungi (Daynes et al. 2013). Plant biomass is positively correlated with soil aggregate stability (Rezaei et al. 2006), as well as plant cover (Bird et al. 2007) and plant roots (Pérès et al. 2013). Conversely, the aggregation and stability directly affect plant growth, since these properties regulate the supply of oxygen and water in the soil (Meyles et al. 2006). Holeplass et al. (2004) reported that crop rotations that include fallow or multiple cultivations decrease the structural stability, but growing plants with extensive root systems and with minimum cultivation improves the stability of aggregates. Jagadamma et al. (2008) indicated that the inclusion of soybean in a rotation with corn has been shown to increase soil aggregate stability, compared to corn continuous cultivation.

Soil porosity is widely recognized as one of the best indicators of soil structure quality (Pires et al. 2005). Porosity is a measure of the void spaces in a material as a fraction (volume of voids to that of the total volume), and pore size distribution provides a direct, quantitative estimate of the ability of a soil to store root-zone water and air necessary for plant growth (Reynolds et al. 2002). Characterization of the pore system provides ballistic basis for understanding the retention and movement of water in soil and, moreover, allows to evaluate the impact of agricultural activities and to quantify some aspects of soil degradation, such as soil compaction and soil crusting (Pagliai and Vignozzi 2002). Pore characteristics are strongly linked to soil physical quality, namely bulk density and macro-porosity are functions of pore volume, while soil porosity and water release characteristics directly influence a range of soil physical indices including soil aeration capacity, plant available water capacity, and relative field capacity (Reynolds et al. 2009).

Stone and Silveira (2001) indicated that crop rotations composed of soybean and wheat resulted in the highest micro-porosity values and the lowest macro-porosity values, whereas the crop rotation composed of upland rice associated with calopogonium and common bean showed the highest macro-porosity value and the lowest micro-porosity value. Furthermore, comparison between three-crop rotation, namely no-tillage spring barley–spring wheat, no-tillage spring wheat–chemical fallow, and traditional winter wheat–summer fallow rotations, revealed that no-tillage spring barley–spring wheat rotation resulted in larger and/or more continuous pores in the upper soil profile (Feng et al. 2011).

Soil Water

Soil water infiltration is the rate at which water enters the soil surface and moves through soil depth (Joel and Messing 2001). Infiltration rate may change significantly with soil use, management, and time (O’Farrell et al. 2010). Water infiltration affects crop production and the volume, transport route, and quality of agricultural drainage (Mukhtar et al. 1985). Water infiltration rate is affected by the initial water content, soil surface conditions, saturated hydraulic conductivity, pore volume and size distribution, the presence of stratified horizons, distance from water source to the wetting front, texture and type of clay (Pagliai et al. 2004). Corbeels et al. (2014) indicated that improved water infiltration and higher soil organic matter resulted in higher crop yields. Furthermore, water holding capacity is an important property in maintaining soil fertility (Reynolds et al. 2002) and essential for plant growth (Brady 1990). The amount of soil water that can be used by the plant varies, due to characteristics of the soil including porosity, field capacity, lower limit of plant available water and hence plant available water capacity, macro-pore, in addition to the plant root distribution and depth (Reynolds et al. 2002).

The use of agricultural gypsum affects soil water characteristics (Escudero et al. 2015) by increasing surface soil water permeability and increasing hydraulic conductivity (Nan et al. 2016), particularly in soils with a high sodium content (Vasconcelos et al. 2013). Most studies emphasis the indirect action of gypsum that improves soil chemical properties, favoring root growth in deeper soil layers (Borges and Pires 2012) and conditioning soil biological activity. This improved root growth favors greater absorption of water by plants and minimizes the effects of drought on the crops (Zandoná et al. 2015). Other physical soil properties, such as soil bulk density and porosity, can be affected by the adequate soil management, which create favorable conditions to increase aggregation and porosity of the soil, resulting in better aeration and water infiltration.

Feng et al. (2011) indicated that using no-tillage spring barley–spring wheat resulted in higher infiltration and saturated hydraulic conductivity, compared to no-tillage spring wheat–chemical fallow, and traditional winter wheat–summer fallow rotations. Kazula et al. (2017) indicated that three corn-based rotations, namely continuous corn, corn–soybean, and corn–soybean–wheat were implemented, where all residues were retained on the field after harvest to study soil water retention, and plant available water. The results indicated that continuous corn and corn–soybean–wheat rotations had greater water content and plant available water across soil water retention tensions than corn–soybean rotation.

Bulk Density

Bulk density is an interactive result of soil structure, texture, organic carbon, and applied pressure on soil (Velayutham 2012). Bulk density is routinely assessed in agricultural systems to characterize the state of soil compactness in response to land use and management (Hakansson and Lipiec 2000). Soil compaction alters soil moisture status, aeration, and root performance (Gomez et al. 2002). There is a negative correlation between bulk density and soil organic matter (Weil and Magdoff 2004), where loss of organic carbon may lead to increase in bulk density, hence making soil more prone to compaction via land management activities (Birkas et al. 2009). Increasing compaction of soil means increasing bulk density which in turn decreases porosity and void ratio (Keller and Håkansson 2010). Furthermore, there are significant relationships between soil properties, such as field moisture content and bulk density (Heuscher et al. 2005). Soil compaction is characterized by increased bulk density, decreased porosity (macro-porosity), reduced water infiltration into the soil, and decreased the water storage capacity of the soil (Meyles et al. 2006).

Blanco-Canqui and Lal (2004) reported that crop rotations that generate greater soil organic content lead to a decrease in bulk density by incorporating a less dense material. Karlen et al. (2006) reported higher bulk density values for continuous corn cultivation and three-year corn–soybean–wheat rotation, compared with extended rotations that incorporated oat or pasture. Feng et al. (2011) indicated that using no-tillage spring barley–spring wheat resulted in lower bulk density, compared to no-tillage spring wheat–chemical fallow, and traditional winter wheat–summer fallow rotations.

Soil Chemical Properties

Soil chemical properties are important in planning for fertilizer application. The chemical composition of the soil is determined by the weathering of the parent material by water. Some chemicals are leached into the lower soil layers where they accumulate, such as chlorides and sulfates, whereas more insoluble chemicals are left in the upper layers of the soil, such as calcium, sodium, magnesium, and potassium (Allen et al. 2011).

Soil pH

Delgado and Gomez (2016) indicated that soil pH is that of the soil solution that is in equilibrium with protons (H+) retained by soil colloids (clays, organic matter, oxides). Soil pH identifies trends in change for a range of soil biological and chemical functions including acidification, salinization, crop performance, nutrient availability and cycling and biological activity (Allen et al. 2011). Root-mediated pH changes in the rhizosphere depend on initial pH, plant species, and nutritional constraints to which plants can respond (Hinsinger et al. 2003). A pronounced acidification in the rhizosphere of oilseed rape was found, whereas pH increased in the rhizosphere of winter wheat was observed (Kotková et al. 2008). Soil pH has a great effect on the availability of residual nutrients in soil, as well as on those added via fertilizer (Hinsinger et al. 2003). Neugschwandtner et al. (2014) indicated that a lower pH value was found in rotation contained oilseed rape root exudates and ongoing decomposition of oilseed rape residues, whereas in rotation contained wheat higher value of pH was found. A decrease of pH is among the short-term changes of soil properties, which can result during decomposition of crop residues due to production of organic acids and microbial respiration (Hulugalle and Weaver 2005).

Soil Electrical Conductivity and Cation Exchange Capacity

Soil electrical conductivity (EC) of the saturation extract of the soil is the base for classification of saline soils and the assessment of the negative effects of salinity on crops (Delgado and Gomez 2016). Soil electrical conductivity (EC) is a measure of salt concentration, and it considered a reliable easily measured indicator of soil quality and health (Arnold et al. 2005). It can inform about trends in salinity, crop performance, nutrient cycling (particularly nitrate), and biological activity (Delgado and Gomez 2016). EC has been used as a chemical indicator to inform about soil biological quality in response to crop management practices (Gil et al. 2009). EC along with pH can act as a surrogate measure of soil structural decline especially in sodic soils (Arnold et al. 2005).

Soil cation exchange capacity (CEC) is considered an important determinant of soil chemical quality, particularly the retention of major nutrient cations, namely Ca, Mg and K, as well as immobilization of potentially toxic cations, namely Al and Mn (Ross et al. 2008). It is measured by the amount of cations (equivalents or moles of charge) which can be extracted by a high concentrated cation solution (usually, 1 M K + or NH4+) (Delgado and Gomez 2016).

Sainju et al. (2015) implemented five different crop rotations (no-till continuous spring wheat, spring till continuous spring wheat, fall and spring till continuous spring wheat, fall and spring till spring wheat–barley followed by spring wheat–pea, and spring till spring wheat–fallow, traditional system) to study the effect of long-term cultivation of these rotations on EC and CEC among other chemical soil properties. The results showed that soil CEC at 0–7.5 cm depth was lower in spring till spring wheat-fallow rotation than no-till continuous spring wheat, spring till continuous spring wheat, fall and spring till continuous spring wheat, and fall and spring till spring wheat–barley followed by spring wheat–pea rotations. At 7.5–15, 15–30, 30–60, 60–90, and 90–120 cm depth, CEC was not different among the rotations and averaged 13.6, 22.9, 31.1, 33.5, and 33.5 cmol_c/kg, respectively. The CEC was greater under continuous wheat than wheat-fallow rotation at 0–7.5 cm depth. In contrast to CEC, EC at 90–120 cm depth was greater in fall and spring till continuous spring wheat and fall and spring till spring wheat–barley rotation followed by spring wheat–pea rotation. At 0–7.5, 7.5–15, 15–30, 30–60, and 60–90 cm depth, EC was not different among treatments and averaged 0.19, 0.17, 0.24, 0.29, and 0.34 dS/m, respectively.

Soil Biological Properties

Soils host a complex web of organisms, which can influence soil evolution and specific soil physical and chemical properties. Soil biological properties are interconnected with other soil physical and chemical properties; e.g., aeration, soil organic matter, or pH affect the activity of many microorganisms in soils, which in turn perform relevant activities in carbon and nutrients cycling (Delgado and Gomez 2016). Management can significantly affect biological properties in soils, especially soil microbial activity, which can be greatly increased by improved drainage, liming, or organic amendments (Ewing and Singer 2012).

Soil Organic Matter

Soil organic matter is one of the most complex and heterogeneous components of soils, which vary in their properties, functions, and turnover rates (Haynes 2008). Weil and Magdoff (2004) indicated that soil organic matter comprises an extensive range of living and non-living components. Organic matter is a particularly important component of soils in agricultural systems because it provides nutrients to crops when decomposed and increases nutrient holding capacity and water holding capacity when built up (Lal 2004). Janzen (2006) indicated that encouraging decomposition of organic matter to liberate nutrients that can be taken up by crops in the short term. The main indicators for evaluating soil organic matter status include soil organic contents, since it comprises about 50% of soil organic matter; organic nitrogen, since it is closely associated with organic carbon and is the most important nutrient for plant productivity; and readily mineralizable carbon and nitrogen (Haynes 2008). Nutrients in the soil needed for crop production are released from the decomposition of the fast cycling, particulate organic matter fraction, dominated by partially decomposed organic matter (Lehmann and Kleber 2015). On the other hand, the slow-cycling, mineral-associated soil organic matter fraction, where carbon stabilizes for storage of atmospheric CO_2, nutrient retention, and water holding capacity, where the mineral-associated fraction is formed primarily from carbon compounds that are assimilated by soil microbes, converted into microbial biomass, and stabilized on the charged surfaces of mineral soil particles in the form of microbial encompass and microbial exudates (Cotrufo et al. 2013).

Heenan et al. (2004) reported that soil organic matter serves as a nutrient reservoir, which impacts soil aggregation. They concluded that from a long-term rotational study, stubble retention in legume–wheat rotation maintained higher levels of soil organic matter than stubble burning. Crop rotation can have a major impact on increasing soil organic matter levels (Carter et al. 2003). Furthermore, Masri and Ryan (2006) reported that rotations contained medic (Medicago sativa) and vetch (Vicia faba), significantly increased soil organic matter, compared to continuous wheat or wheat/fallow. Liu et al. (2005) also showed that wheat and sweet clover rotation not only increased the soil organic matter content in all soil depths, but also had the greatest amount of soil organic contents and had a decrease in soil bulk density. A large increase in soil organic content level for a rotation compared to a monoculture maize system was found by Gregorich et al. (2001). Gil and Fick (2001) indicated that soil inorganic N of alfalfa monoculture was threefold to fivefold higher than the alfalfa, red clover, and gama grass–alfalfa mixture, but it was 30–50% lower than in gama grass monoculture. Abd El-Hady et al. (2000) indicated that when Egyptian clover preceded rice in a three-year crop rotation in salt-affected soil, soil organic matter was increased in the end of the three years. Furthermore, Quintern et al. (2006) reported that the highest organic matter content was found in the crop rotation containing alfalfa.

Crop rotations can increase total soil C and N concentrations over time, which may further improve soil productivity (Kelley et al. 2003). Witt et al. (2000) found that the replacement of dry season rice by maize in a rice–rice rotation caused a reduction in soil C and N due to a 33–41% increase in the estimated amount of mineralized C and N during the dry season. As a result, there was 11–12% more C sequestration and 5–12% more N accumulation in soils continuously cropped with rice than in the maize–rice rotation with the greater amounts sequestered in N-fertilized treatments. Zuber et al. (2018) evaluated the effect of four rotations, namely continuous corn, corn–soybean, corn–soybean–wheat, and continuous soybean on soil organic carbon content. They found that corn–soybean–wheat rotation increased soil organic carbon, compared to other rotations. They also indicated that inclusion of crops with high C:N residues supports higher C and N content in the top 20 cm of the soil. Yang and Kay (2001) found that continuous alfalfa had the greatest average soil organic content concentration, than continuous corn. In a three-year cropping sequence study, repeated for five cycles in Saskatchewan from 2005 to 2011, showed that both pulse- and summer fallow-based systems enhances soil N availability, but the pulse system employs biological fixation of atmospheric N2, whereas the summer fallow system relies on 'mining' soil N with depleting soil organic matter. Inclusion of the pulse system increased total grain production by 36%, improved protein yield by 51%, and enhanced fertilizer-N use efficiency by 33% over the summer fallow system. Diversifying cropping systems with pulses can serve as an effective alternative to summer fallowing in rain-fed dry areas (Gan et al. 2015).

Veneklaas et al. (2003) indicated that several legume crops, such as chickpea and white lupine, can mobilize soil and fertilizer P through the exudation of organic acid anions, such as citrate and malate and other compounds from their roots. Hocking and Randall (2001) reported an improvement in growth and P nutrition of less P-efficient crops following organic-anion exuding legumes. Khadr et al. (2004) indicated that application of organic manure to crops grown in three-year rotation implemented in low fertile soil increases soil organic matter and increases available soil N, P, and K, compared to no manure application.

Soil Microbial Biomass

Soil microbial biomass is the living component of soil organic matter and it is considered the most labile carbon pool in the soil (McDaniel and Grandy 2016). Furthermore, it is a sensitive indicator of changes in soil processes, with links to soil nutrient and energy dynamics, including mediating the transfer between soil organic content fractions (Saha and Mandal 2009). Soil microbial biomass has been shown to be responsive to short-term environmental changes (Haynes 2008). Declines in plant diversity will likely reduce soil microbial biomass, alter microbial functions, and threaten the provisioning of soil ecosystem services (McDaniel and Grandy 2016).

Crop rotations have been shown to have large positive effects on soil C, N, and microbial biomass (McDaniel et al. 2014). The benefit of crop rotations laid in greater diversity of plant inputs to soil organic matter over time, which enhances belowground biodiversity (Grandy and Robertson 2007). Thus, crop rotations have been shown to increase soil microbial and faunal biodiversity (Tiemann et al. 2015) and increase microbial carbon use efficiency (Kallenbach et al. 2015). McDaniel and Grandy (2016) indicated that increasing number of crops in the crop rotation (biodiverse cropping systems) increased microbial biomass carbon by 28–112% and N by 18–58%, compared to low-diversity systems (crop rotation with low number of crops).

Crop Rotations in Egypt

Crop Rotation Under Rain-Fed Condition

Five two-year crop rotations were implemented in North Egypt under rain-fed condition to assess fertility build up, as result of implementing these rotations. These rotations were barley–fallow, wheat–wheat, barley–barley, barley–pea, and barley—lentil. The results indicated that the highest soil organic matter was obtained when barley–pea rotation was implemented, where organic matter was increased by 47% after harvest. The values of N, P, and K were increased by 73, 300, and 19%, respectively, under barley–pea rotation (Abd El-Hadi et al. 2002).

Crop Rotations in the Agro-climatic Zones of Egypt

Egypt was divided into five agro-climatic zones in the old land surrounding the Nile Delta and Valley by Ouda and Noreldin (2017) using ETo data from 2005 to 2014 (Fig. 4.1).

Crop Rotation in the Second Agro-climatic Zone

Khadr et al. (2004) implemented two three-year crop rotations (prevailing and proposed) to study the change in organic matter and macronutrients in sandy soil (98.5% sand) with very poor content of organic matter (0.25%) and available nitrogen (9.25 ppm). In the prevailing three-year crop rotation, only three crops were cultivated, namely wheat, groundnut, and clover (Fig. 4.2). The continuous cultivation of groundnut in the prevailing crop rotation resulted in depletion of nutrients from the soil and results in spread of nematodes.

The proposed crop rotation was characterized by diversity in the cultivated crops (Fig. 4.3). In this rotation, groundnut is cultivated once every three years to reduce the spread of nematodes. In the first section of the proposed rotation, clover preceded groundnut to improve soil quality. In the second section, wheat and sesame were

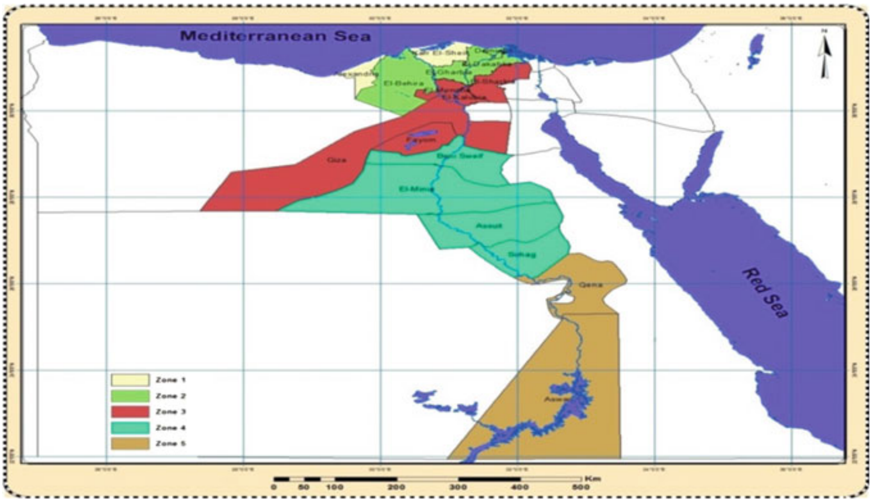

Fig. 4.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

Year 1	Year 2	Year 3
Wheat Ground nut	Clover Ground nut	Wheat Ground nut
Wheat Ground nut	Wheat Ground nut	Clover Ground nut
Clover Ground nut	Wheat Ground nut	Wheat Ground nut

Fig. 4.2 Prevailing crop rotation in the sandy soil of the second agro-climatic zone

Year 1	Year 2	Year 3
Clover Ground nut	Pea Sunflower Maize	Wheat Sesame
Wheat Sesame	Clover Ground nut	Pea Sunflower Maize
Pea Sunflower Maize	Wheat Sesame	Clover Ground nut

Fig. 4.3 Proposed crop rotation in the sandy soil of the second agro-climatic zone

cultivated, where both are non-host nematode. In the third section, three crops were cultivated, where pea followed by sunflower followed by maize. Both sunflower and maize are non-host nematode.

The results indicated that the soil organic matter after the three years was increased by 32%. Available soil N, P, and K were increased by 6, 46, and 20%, respectively, compared to its values in the prevailing crop rotation.

This study was followed by another cycle of the proposed three-year crop rotation, where another increase in soil organic matter and available soil N, P, and K were detected. Soil organic matter was increased by 48%. Available soil N, P, and K were increase by 197, 200, and 165%, respectively, compared to the prevailing crop rotation (Zohry 2017).

In another experiment implemented in salt-affected soil in North Egypt, high reduction in soil pH, EC, and ESP was found after the implementation of diversified three-year crop rotation, compared to prevailing two-year crop rotation. The application of gypsum and manure in both rotations resulted in reductions in soil pH, EC and ESP by 10, 41, and 30%, respectively, in the three-year crop rotation, whereas the percentage of reductions for soil pH, EC and ESP were 6, 31 and 24%, respectively, in the two-year crop rotation (Kamel et al. 2010).

Crop Rotation in the Fourth Agro-climatic Zone

In experiments conducted by Abd El-Hadi et al. (2000) in the fourth agro-climatic zone, two cycles of three-year crop rotations (prevailing and proposed) were implemented on clay soil of the fourth agro-climatic zone. The aim of this experiment was to improve soil fertility by intensive cropping systems. The prevailing crop rotation (Fig. 4.4) included clover (2 cuts) followed by cotton in the first section. Wheat proceeded with maize in the second section, where both are exhausting crops to the soil and faba bean preceded tomato in the third section.

The proposed rotation contained more legume crops, namely soybean, cowpea, and faba bean (Fig. 4.5) to increase soil organic matter content and to increase the values of soil available N, P, and K. In the first section of the rotation, cotton relay intercropped on onion system was implemented (Zohry 2005). Details on this intercropping system are presented in Chap. 3.

In the second section of the rotation, three-crop sequence was implemented where soybean was cultivated between wheat and cowpea. In this system, wheat was cultivated in November and harvested in April, and then soybean was cultivated and harvested in July, where cowpea was cultivated. The third section of the rotation contained two crops, namely faba bean and summer tomato.

Year 1	Year 2	Year 3
Clover (2 cuts) Cotton	Wheat Maize	Clover (2 cuts) Cotton
Wheat Maize	Faba bean Tomato	Wheat Maize
Faba bean Tomato	Clover (2 cuts) Cotton	Faba bean Tomato

Fig. 4.4 Prevailing crop rotation in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Cotton relay intercropped with onion	Wheat Soybean cowpea	Faba bean Tomato
Wheat Soybean Cowpea	Faba bean Tomato	Cotton relay intercropped with onion
Faba bean Tomato	Cotton relay intercropped with onion	Wheat Soybean Cowpea

Fig. 4.5 Suggested crop rotation in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Clover (one cut) Cotton	Faba bean Soybean	Wheat Maize
Wheat Maize	Clover (one cut) Cotton	Faba bean Soybean
Faba bean Soybean	Wheat Maize	Clover (one cut) Cotton

Fig. 4.6 First crop rotation, cotton preceded by cereal and cereal

The results indicated that the proposed rotation increases soil fertility, where N, P, and K values were increased by 18, 32, and 24% in the first cycle, respectively, compared to the prevailing rotation. Furthermore, after the second cycle, N, P, and K values were increased by 15, 47, and 18%, respectively, compared to the prevailing rotation. Furthermore, soil organic matter was increased by 17% after the second cycle, compared to the first cycle.

Moreover, Farghly and Zohry (2002) implemented four three-year crop rotations in clay soil to study the effect of crop sequence before cotton within the crop rotation on soil available N, P, and K. Figure 4.6 presents the first crop rotation. In this rotation, cotton was cultivated after wheat in the winter and maize in the summer. In this case, the results indicated that soil available N, P, and K was reduced by 31, 5, and 8%, respectively, after the end of the three years.

In the second crop rotation, cotton was cultivated after faba bean in the winter and maize in the summer (Fig. 4.7). Under these circumstances, the available N, P, and K in the soil were reduced by 13, 5, and 5%, respectively, after the end of the three years.

In the third crop rotation, cotton was cultivated after wheat in the winter and soybean in the summer (Fig. 4.8). The available N, P, and K in the soil in the end of the three years were increased by 38, 34, and 2%, respectively.

In the fourth crop rotation, cotton was cultivated after faba bean in the winter and soybean in the summer (Fig. 4.9). The soil available N, P, and K in the soil in the end of the three years were increased by 50, 64, and 5%, respectively.

In another experiment, Abou-Keriasha et al. (2012) conducted two cycles of crop rotations, each for three years on clay loamy soil to compare between the three-year

Year 1	Year 2	Year 3
Clover (one cut) Cotton	Wheat Soybean	Faba bean Maize
Faba bean Maize	Clover (one cut) Cotton	Wheat soybean
Wheat Soybean	Faba bean Maize	Clover (one cut) Cotton

Fig. 4.7 Second crop rotation, cotton preceded by legume and cereal

Year 1	Year 2	Year 3
Clover (one cut) Cotton	Faba bean Maize	Wheat soybean
Wheat soybean	Clover (one cut) Cotton	Faba bean Maize
Faba bean Maize	Wheat Soybean	Clover (one cut) Cotton

Fig. 4.8 Third crop rotation, cotton preceded by cereal and legume

Year 1	Year 2	Year 3
Clover (one cut) Cotton	Wheat Maize	Faba bean soybean
Faba bean soybean	Clover (one cut) Cotton	Wheat Maize
Wheat Maize	Faba bean soybean	Clover (one cut) Cotton

Fig. 4.9 Fourth crop rotation, cotton preceded by legume and legume

Year 1	Year 2	Year 3
Clover Cotton	Faba bean Maize	Wheat Maize
Wheat Maize	Clover Cotton	Faba bean Maize
Faba bean Maize	Wheat Maize	Clover Cotton

Fig. 4.10 Prevailing crop rotation in the fourth agro-climatic zone

prevailing rotations cultivated by the farmer in the surrounding area (Fig. 4.10) and two proposed intensive crop rotations (Figs. 4.10 and 4.11) on increasing soil organic matter and soil available N, P, and K. The prevailing crop rotation was characterized by cultivation of mono crops in each growing season, in the three years and in the two cycles.

After the harvest of the crops cultivated in the second cycle in the proposed crop rotation (Fig. 4.11), soil organic matter content was increased by 22%, compared to the prevailing crop rotation. Furthermore, the value of soil available N, P, and K were increased by 41, 39, and 31%, respectively, compared to the prevailing crop

Year 1	Year 2	Year 3
Cotton relay intercropped on onion then sesame intercropped with cotton	Faba bean Maize Fahl clover	Wheat Cowpea intercropped with maize
Wheat Cowpea intercropped with maize	Cotton relay intercropped on onion then sesame intercropped with cotton	Faba bean Maize Fahl clover
Faba bean Maize Fahl clover	Wheat Cowpea intercropped with maize	Cotton relay intercropped on onion then sesame intercropped with cotton

Fig. 4.11 First proposed rotation in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Cotton relay intercropped on wheat then cowpea intercropped with cotton	Faba bean intercropped with onion Cowpea intercropped with maize	Faba bean intercropped with wheat Soybean intercropped with maize
Faba bean intercropped with wheat Soybean intercropped with maize Fahl clover	Cotton relay intercropped on wheat then cowpea intercropped with cotton	Faba bean intercropped with onion Cowpea intercropped with maize
Faba bean intercropped with onion Cowpea intercropped with maize	Faba bean intercropped with wheat Soybean intercropped with maize	Cotton relay intercropped on wheat then cowpea intercropped with cotton

Fig. 4.12 Second proposed rotation in the fourth agro-climatic zone

rotation. These results were attributed to implementing cowpea intercropped with maize system and three-crop sequence, namely maize cultivated between faba bean and fahl clover. Details on cowpea intercropped with maize system (Hamd-Alla et al. 2014) are presented in Chap. 3, whereas in the three-crop sequence, maize was cultivated between two legume crops, namely faba bean and fahl clover (a short season variety of clover).

In the second proposed crop rotation, soil organic matter content was increased by 38%, compared to the prevailing crop rotation. In addition, available N, P, and K were increased by 43, 45, and 35%, respectively, compared to the prevailing crop rotation (Fig. 4.12). These results attributed to increase the number legume crops in the rotation. In the first section of the rotation, cowpea was intercropped with cotton after wheat was harvested.

In the second section of the rotation, faba bean was intercropped with wheat in the winter season (Abdel-Wahab and El Manzlawy 2016). In the summer season, soybean was intercropped with maize (Sherif and Gendy 2012). Additionally, fahl clover was cultivated as an early winter crop. More details on these intercropping systems are presented in Chap. 3.

In the third section the rotation (Fig. 4.12), faba bean was intercropped with onion in the winter season (Abou-Keriasha et al. 2012). In addition, in the summer season, cowpea was intercropped with maize. More details on the intercropping systems are presented in Chap. 3.

Conclusion

Review of the previous research, done nationally and internationally, on the effect of crop rotations on soil fertility revealed that it can improve physical, chemical, and biological soil properties. Crop rotation improves soil structure and reduces bulk density. Crop rotation improves soil pH and reduces soil EC. Crop rotation increases soil organic matter content and soil microbial biomass. Furthermore, the sequence of the crops within the rotation affects nutrients cycling.

The review of the implemented crop rotations in Egypt showed improvement in soil fertility, when legume crops included in the rotation. The implemented crop rotations in Egypt improved soil properties and increased its sustainability. This advantage of using crop rotation indirectly and positively reflected on crops production, which directly and positively reflected on food security.

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Chapter 5
Crop Rotation Defeats Pests and Weeds

Introduction

Arable crops are grown by farmers in patterns according to time and space. A crop rotation could be described as "growing crops in a recurring sequence on the same field" (Thenail et al. 2009). One of the most important benefits of applying crop rotation was to prevent the spread of pests, weeds, and diseases through rotating the crops, where inclusion of breaking phases decreases its population dynamics (Kirkegaard et al. 2008). Furthermore, neglecting crop rotation results in an increase in pest populations, the accumulation of toxic substances, the depletion of mineral nutrients, degradation in soil fertility, and destruction of soil structure (Katan 2010).

Crop rotation deals with plant health in general rather than with controlling a specific disease, although certain crop sequence might be more effective in reducing the incidence of a specific disease than others. Crop rotation could also be regarded as insurance against the rise of unknown pathogens (Katan 2003). Unintended introduction of *Diabrotica virginifera* pest as a result of maize growing in a continuous sequence emphasis the roll of rotation practice in controlling it (Gray et al. 2009). Under this situation, crop rotations were mentioned as a first key element for integrated crop protection (EU 2009).

An effective crop rotation deployment might limit, and in some cropping years even eliminate, the need for herbicide applications to control the dominant weed species (Gonzalez-Diaz et al. 2012). Changes in crop rotation and herbicide use could change the weed seed banks in arable soils (Squire et al. 2000). The impact of rotation design on weed community density is enhanced by no-till. Crop tolerance to weeds is improved by systems of cultural tactics, where three tactics are combined together (Anderson 2007). Replacing spring cereals with winter cereals resulted in a 25% reduction in weed density and species diversity (Hald 1999).

The important role of crop rotation in defeating pests and weeds was discussed in this chapter. Furthermore, the implemented crop rotations in Egypt to control pests and weeds were also discussed.

S. Ouda et al., *Crop Rotation*, https://doi.org/10.1007/978-3-030-05351-2_5

Pests and Diseases Control by Crop Rotation

Many pests and diseases can be controlled by crop rotations. *Fusarium* spp. is common fungal pathogens that infect a number of field and vegetable crops. Crop rotation, genetic resistance, and fungicides are the primary methods used for managing these pathogens (Marburger et al. 2014). Even with the use of resistant varieties, the use of a non-host crop can also help reduce the risk of disease development (Krupinsky et al. 2002).

Furthermore, root and crown rot, caused by *Rhizoctonia solani*, was an increasing problem for sugar beet cultivation in Europe and several other countries, such as the USA (Garcia et al. 2001). It was also documented that pre-crop host plants, such as sorghum, soybean, and maize increase disease severity in sugar beet (Windels and Brantner 2004). An important approach to control the disease is the design of crop rotations with non-host crop, such as dry bean (Engelkes and Windels 1996). Buhre et al. (2009) indicated that crop rotation of sugar beet with non-host plants and cultivation of resistant sugar beet cultivars are adequate means for integrated *R. solani* control.

A long-term crop rotation study was initiated in 1994 with 12 double-cropping sequences incorporating wheat, rye, or canola, and soybean or grain pearl millet. The purpose was to identify sustainable alternatives to the continuous wheat–soybean system that would provide acceptable management of take-all root rot of wheat caused by *Gaeumannomyces graminis var tritici.* This disease became a serious problem with the widespread adoption of wheat–soybean double-cropping in the southeastern USA during the past 30 years. The results showed that take-all was severe in rotations with continuous wheat each year. Soybean or pearl millet had little effect on yield loss due to take-all in a subsequent wheat crop. A one-year rotation with canola significantly reduced take-all incidence and severity. However, canola in the rotation had a greater effect in suppressing disease severity than disease incidence; thus, it is valuable rotational crop for management of take-all in wheat in the southeastern USA (Cunfer et al. 2006).

Davis et al. (2009) indicated that fusarium crown rot of wheat is a yield-limiting disease in the dry land wheat-production area of the intermountain Pacific Northwest and is exacerbated in water-stressed plants induced by over fertilizing with nitrogen. This disease has become more important for spring wheat in continuous cropping areas. Thus, they investigated the influence of the previous (rotation) crop (winter and spring canola, barley, or peas) on the incidence of diseases, grain yield, grain protein concentration, and populations of fusarium in the soil. The previous crop had small, but significant, effects on disease; however, it was not consistent from year to year.

Gracia-Garza et al. (2002) reported that two-year crop rotations of corn or winter wheat with soybean had a significant effect on reducing production of apothecia by *sclerotia* of *Sclerotinia sclerotiorum* in soybean fields. Germination of *sclerotia* was decreased in crop rotations compared to continuous soybean. Dill-Macky and Jones (2000) found that fusarium head blight of wheat could be significantly reduced with a wheat–soybean rotation.

The effects of a four-year crop rotation and two tillage systems on blackleg disease of canola were studied by Guo et al. (2005) in a field experiment carried out from 1999 to 2002 at Carman, Manitoba. Crops in the rotation were canola, wheat, and flax. Diseased stem incidence and severity in 2001 and 2002 were significantly lower when canola was rotated with wheat and rotated with wheat and flax under both tillage systems. The continuous canola rotation had a higher disease incidence than canola, wheat, canola and canola rotation; canola, wheat, flax and canola rotation and canola, canola, wheat and canola rotation.

Stetina et al. (2007) found that following two years of corn production, reniform nematode populations remained below damaging levels to the cotton plants, compared to continuous cotton planting. However, cotton following just one year of corn would have reniform nematode populations rebound to damaging levels toward the end of the growing season. Considering plants with allelopathic effects, such as rye and triticale permits sustainable weed management while reducing the impact of agriculture on the environment (Tabaglio et al. 2008).

Changes in population levels of *Meloidogyne hapla*, *Meloidogyne incognita*, *Pratylenchus coffeae*, and *Pratylenchus penetrans* were studied in 12 strawberry fields in the Dahu region of Taiwan by Chen and Tsay (2006). Ten potential rotation crops and two cultural practices were evaluated for their effect on nematode populations and influence on strawberry yield. Rotation with rice or taro and the cultural practice of flooding and bare fallowing for four months were found to reduce nematode soil populations to two or fewer nematodes per 100 ml soil. Average strawberry yields increased between 2 and 6% following taro, compared to the bare fallow treatment. Corn suppressed *M. incognita* and *M. hapla* populations and resulted in an increase in strawberry yield compared to bare fallow. Other phytopathogens also presented in these fields limited to taro, as the rotation choice for nematode management. Furthermore, Esser et al. (2015) indicated that soil-dwelling insects are severe pests in many agro-ecosystems. These pests have cryptic life cycles, making sampling difficult and its damage is high. Furthermore, wireworms, the subterranean larvae of click beetles (Coleoptera: Elateridae), have re-emerged as problematic pests in cereal crops in the Pacific Northwestern United States. They also added that switching from continuous spring wheat to a winter wheat and summer fallow rotation may aid in wireworm management. Traditional rotations of rice–soybean, with winter wheat grown between the two summer annuals, were observed to have the highest levels of two serious fungal pests, especially with high N-fertility levels. These two serious fungal pests in rice production areas of the USA appear to be best controlled when rice is grown in three-year rotations with soybean and corn between rice crops (Brooks 2011).

Crop Rotation to Reduce Weed Population

Weeds are ubiquitous to most crops. Most agricultural soils contain millions of weed seed per hectare, and if left unmanaged, weeds greatly reduce crop yields by competing with the crop for nutrients, light, and water (McErlich and Boydston 2014). Despite advances in control technologies, weeds have retained their rank as the most damaging of crop pests because weed communities continue to adapt in response to new management measures (Sosnoski and Cardina 2006). Crop rotation is an important potential management approach for regulating weed seed populations in the soil of organic farming systems (Teasdale et al. 2004).

Rotations included two-year intervals of cool and warm-season crops have enabled conventional producers to eliminate herbicide use in three crops out of four because weed density was so low (Anderson 2008). Longer rotations with more phonologically diverse crops can reduce seed bank populations and abundance of important annual broadleaf weed species in organic production systems (Teasdale et al. 2004).

Crop rotations with multiple years of alfalfa reduce herbicide-resistant to giant ragweed emergence, while maintaining a similar level of seed bank depletion as other crop rotations common to the Midwestern United States (Goplen et al. 2017). Crop rotation affects the soil seed bank and weed flora (Marshall et al. 2003). Changes in crop rotation and herbicide use could change the weed seed banks in arable soils (Squire et al. 2000). Alternate weed-susceptible and weed suppressing crops and grow crops with different pest and disease susceptibilities in the crop rotation interrupt weed life cycle to reduce populations and decreasing likelihood of developing herbicide resistance in weeds (Malik 2010). Mertens et al. (2002) studied how different crop rotation sequences, crop fractions, and lengths in a two-crop species rotation affect the growth rate of the weed species *Persicaria maculosa* (formerly named *Polygonum persicaria*) and found that changing crop rotation sequences reduced weed population growth rate. Gonzalez-Diaz et al. (2012) indicated that crop rotation implemented at the landscape level has great potential to control weeds, whereby both the number of crop species and the cropping sequence within the crop rotation have significant effects on both the short-term and long-term weed population densities.

Different rotations that include crops with different life cycles, such as wheat then maize and wheat or sugar beet could lead to additional benefits of reducing the weed seed bank (Koocheki et al. 2009). Rotations comprised of two cool-season crops followed by two warm-season crops are the most disruptive of weed population growth. The impact of rotation design on weed community density is enhanced by no-till (Anderson 2007). Furthermore, continuous winter wheat fields showed more annual grass weeds, but broadleaf weeds were more abundant in sugar beet-winter wheat rotation (Koocheki et al. 2009). Meiss et al. (2010) indicated that the frequent harvests of alfalfa reduced populations of annual weeds adapted to corn and soybean by reducing weed seed production and providing year-round ground cover favorable for insects, rodents, and fungi that consume weed seeds. Narwal (2000) reported that the inclusion of summer fodder crops before rice in the rice–wheat rotation provided satisfactory weed control in the succeeding stage of rice and minimized the use of herbicides. Likewise, the replacement of wheat by winter fodder crops (oat and berseem) may also help in the control of winter weeds. Furthermore, sorghum–wheat rotation had strong suppressive effect on weed infestation, where its impact was more visible during second year of experimentation (Shahzad et al. 2016). In addition, incorporating wheat into crop rotations also provides weed control benefits by being planted earlier than corn and soybean and at greater plant densities in narrow rows, causing it to be more competitive with early emerging weeds (Swanton et al. 1999). In continuous wheat cultivation, the highest weed biomass was obtained in heading stage. The greatest weed dry matter in all four wheat growth stages was achieved, whereas the lowest value of weeds was found under wheat–maize–wheat–sugar beet–wheat rotation (Zareafeizabadi and Rostamzadeh 2013).

Teasdale et al. (2004) indicated that the seed banks of smooth pigweed (*Amaranthus hybridus* L.) and common lambs quarters (*Chenopodium album* L.) preceding corn were lower following hay crops cultivation years of the four-year rotation or the wheat cultivation year of the three-year rotation than following the soybean year of the two-year rotation. However, annual grass seed banks preceding corn tended to be higher following the hay crops cultivation years of the four-year rotation than following the wheat year of the three-year rotation or the soybean year of the two-year rotation. Crop sequences beginning with hay crops cultivation had lower smooth pigweed and common lambs quarters seed bank populations than all other sequences.

Crop Rotations in Egypt

Ouda and Noreldin (2017) developed agro-climatic zones in the old land surrounding the Nile Delta and Valley. Their results distinguished five agro-climatic zones as is presented in Fig. 5.1.

Crop Rotation in the Second Agro-climatic Zone

A suggested crop three-year crop rotation was implemented in the sandy soil of the second agro-climatic zone to reduce the incidence of nematode infection in peanut. The prevailing three-year crop rotation in this area included peanut cultivated every year (Fig. 5.2), which result in reduction of peanut yield. Continuous cultivation of peanut results in continuous decline in peanut yield due to deterioration of soil microbial community (Wang and Chen 2005). Furthermore, it reduces the diversity of bacteria in both species and quantity, lower the number of fungi species and increase mold quantity (Xie et al. 2007). Peanut yield was reduced from 4.6 ton per hectare in the first year of the rotation to 0.82 ton/ha in the third year of the rotation, which represent 400% reduction. In addition, faba bean and clover were also included in

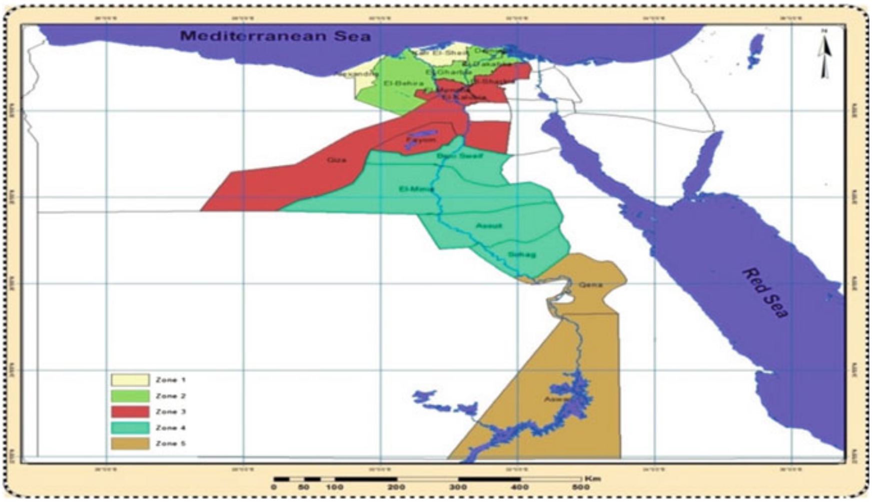

Fig. 5.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

Year 1	Year 2	Year 3
Wheat Peanut	Clover Peanut	Faba bean Peanut
Faba bean Peanut	Wheat Peanut	Clover Peanut
Clover Peanut	Faba bean Peanut	Wheat Peanut

Fig. 5.2 Prevailing crop rotation for peanut in sandy soil of the second agro-climatic zone

the rotation, where these crops are host-nematode. As a result, low productivity of these two crops also occurred.

The suggested three-year crop rotation included non-host nematode crops to control nematode population in the soil, namely maize, sesame, and wheat. In addition, peanut was cultivated every three years (Fig. 5.3).

Year 1	Year 2	Year 3
Clover Maize	Faba bean Sesame	Wheat Peanut
Faba bean Sesame	Wheat Peanut	Clover Maize
Wheat Peanut	Clover Maize	Faba bean Sesame

Fig. 5.3 Proposed crop rotation for peanut in sandy soil of the second agro-climatic zone

The results indicated that after implementing the suggested crop rotation, nematode number was reduced from 8800 nematode/250 g soil to 360 nematode/250 g soil. Consequently, peanut yield was increased to 2.2 ton/ha (Zohry 2017).

In the same zone, another crop rotation was implemented for sugar beet to reduce the incidence of nematode infection. The prevailing crop rotation is presented in Fig. 5.4. In this rotation, sugar beet was cultivated every year, in addition to peanut, where both crops, tremendously increased the nematode population to 9600 nematode/250 g soil. Furthermore, low sugar beet yield was produced, namely 24 ton/ha, with low quality.

In the proposed crop rotation (Fig. 5.5), sugar beet was cultivated every three years, peanut was not cultivated, and the rest of the crops in the rotation are non-host nematode. The nematode population was reduced to 710 nematode/250 g soil. Furthermore, higher sugar beet yield was produced, namely 43 ton/ha, with 80% increase. Moreover, the quality of tubers was also improved (Zohry 2017).

Crop Rotation in the Fourth Agro-climatic Zone

The duration of a crop rotation has an effect on the associated weeds of the cultivated crops. In this context, Toaima (2007) studied the effect of crop rotation duration (one-year, two-year, and three-year rotations) on associated weeds with cotton crop. The one-year crop rotation contained clover (one cut) and cotton repeated every year. In the two-year crop rotation (Fig. 5.6), cotton was repeated once every two years. Under these conditions, the associated weeds with cotton were decreased by 31%, compared to the one-year crop rotation.

In the three-year crop rotation (Fig. 5.7), cotton was repeated every three years. The associated weeds with cotton were reduced by 48%, compared to the one-year crop rotation.

Furthermore, Abou-Keriasha et al. (2012) conducted two cycles of crop rotations, each for three years on clay loamy soil to compare between the three-year prevailing rotation cultivated by the farmer in the surrounding area and two proposed intensive rotations in reducing associated weeds. Figure 5.8 presents the prevailing crop rotation.

Year 1	Year 2	Year 3
Sugar beet Maize	Sugar beet Peanut	Sugar beet Water melon
Sugar beet Peanut	Sugar beet Water melon	Sugar beet Maize
Sugar beet Water melon	Sugar beet Maize	Sugar beet Peanut

Fig. 5.4 Prevailing crop rotation in sandy soil for sugar beet of the second agro-climatic zone

Year 1	Year 2	Year 3
Clover Water melon	Wheat Sesame	Sugar beet Maize
Wheat Sesame	Sugar beet Maize	Clover Water melon
Sugar beet Maize	Clover Water melon	Wheat Sesame

Fig. 5.5 Proposed crop rotation in sandy soil for sugar beet of the second agro-climatic zone

Year 1	Year 2
Clover (two cuts) Cotton	Wheat Maize
Wheat Maize	Clover (two cuts) Cotton

Fig. 5.6 Two-year crop rotation implemented in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Clover (two cuts) Cotton	Faba bean Maize	Wheat Maize
Wheat Maize	Clover (two cuts) Cotton	Faba bean Maize
Faba bean Maize	Wheat Maize	Clover (two cuts) Cotton

Fig. 5.7 Three-year crop rotation implemented in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Clover Cotton	Faba bean Maize	Wheat Maize
Wheat Maize	Clover Cotton	Faba bean Maize
Faba bean Maize	Wheat Maize	Clover Cotton

Fig. 5.8 Prevailing crop rotation in the fourth agro-climatic zone

The first proposed crop rotation presented in Fig. 5.9. After the harvest of the crops cultivated in the second cycle of the first proposed crop rotation, the dry weight of annual weeds associated with wheat, maize, and cotton was significantly reduced by 35, 53, and 57%, respectively, compared to the prevailing crop rotation. This result is attributed to cultivation of fahl clover before wheat in the end of the duration of the rotation reduced the growth of the weeds. In addition, cotton intercropping systems implemented in the first section of the rotation (more details on the intercropping systems presents in Chap. 3) provided yearlong cover and suppress cotton associated weeds. Faba bean preceded maize, in addition to intercropping cowpea with

Year 1	Year 2	Year 3
Cotton relay intercropped on onion then sesame intercropped with cotton	Faba bean Maize Fahl clover	Wheat Cowpea intercropped with maize
Wheat Cowpea intercropped with maize	Cotton relay intercropped on onion then sesame intercropped with cotton	Faba bean Maize Fahl clover
Faba bean Maize Fahl clover	Wheat Cowpea intercropped with maize	Cotton relay intercropped on onion then sesame intercropped with cotton

Fig. 5.9 First proposed rotation in the fourth agro-climatic zone

Year 1	Year 2	Year 3
Cotton relay intercropped on wheat then cowpea intercropped with cotton	Faba bean intercropped with onion Cowpea intercropped with maize	Faba bean intercropped with wheat Soybean intercropped with maize
Faba bean intercropped with wheat Soybean intercropped with maize	Cotton relay intercropped on wheat then cowpea intercropped with cotton	Faba bean intercropped with onion Cowpea intercropped with maize
Faba bean intercropped with onion Cowpea intercropped with maize	Faba bean intercropped with wheat Soybean intercropped with maize	Cotton relay intercropped on wheat then cowpea intercropped with cotton

Fig. 5.10 Second proposed rotation in the fourth agro-climatic zone

maize (more details on the intercropping systems presents in Chap. 3) resulted in the reduction in the associated weeds of maize.

In the second proposed crop rotation (Fig. 5.10), the dry weight of annual weeds associated with wheat, maize, and cotton were significantly reduced by 51, 70, and 66%, respectively, compared to the prevailing crop rotation. These results are attributed to implementing intercropping systems, namely faba bean intercropped with wheat, cotton intercropping systems, and maize intercropped with soybean or cowpea resulted in reducing the density of the associated weeds (more details on the intercropping systems presented in Chap. 3).

Conclusion

Reduction in pests, weeds populations, and diseases is another benefit of implementing crop rotation. In this chapter, we discussed the role that crop rotation plays in preventing the spread of pests, weeds, and diseases. Literature review of the research done on this topic around the world prevailed that inclusion of breaking phases and using certain crop sequence can prevent the incidence of a specific disease, insects, and/or weeds. Furthermore, the implemented crop rotations in Egypt to control pests and weeds were discussed and its results were very successful in reducing weeds and diseases, and consequently improve crops productivities, thus increase food security.

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Chapter 6
Crop Rotation Could Diminish Summer Feed Gap in Egypt

Introduction

Green forage is the main contributor in the feed of livestock. In Egypt, there is a gap in the production of summer forage crops estimated by about 90%. There are several summer forage crops are cultivated in Egypt, such as green maize (darawa), cowpea, sweet corn, and millet. The cultivated area of summer forage crops was estimated by about 88,235 ha, where darawa occupy the highest cultivated area. Because of limited arable land in the Nile Delta and Valley, there is no area available for expansions on summer feed crops. To fill the gap between production and consumption of summer feed crops, two crops could be cultivated, i.e., fahl clover and cowpea.

Fahl clover is a variety of Egyptian clover, which has stem branching ability and cuts only once. It produces more seeds, compared to the other prevailing clover variety, namely Miskawi (Abd El-Naby et al. 2014). Because fahl clover is characterized by rapid growth and large forage yield, it could be cultivated as early winter season starting in September and stays until the beginning of November, where its growing season between 60 and 70 days (Bakheit et al. 2016).

In general, Egyptian clover is the main leguminous forage crop grown in Egypt during the winter season. It plays vital role in the sustainability of Egyptian agriculture. It nourished the soils, suppressing weeds and providing a disease break in cereal-dominated crop rotations (El-Nahrawy 2011). Jabbar et al. (2011) indicated that cultivation of Egyptian clover increased residual soil fertility, residual soil nitrogen, and residual soil organic matter. It forms symbiotic relationships with soil bacterium (Rhizobium sp.) and fixes atmospheric nitrogen adding significant amounts of nitrogen to the soil (Nair 2015). Thus, intensive cropping, where fahl clover could be cultivated after the two major summer crops maize (Zohry et al. 2017b) or rice (Sheha et al. 2014) and before the following winter crop could be implemented to attain these benefits. Using this suggestion, large area of fahl clover could be cultivated, which attain triple benefits: increase soil fertility, increase the production of summer feed, and increase the productivity of the following winter

S. Ouda et al., *Crop Rotation*, https://doi.org/10.1007/978-3-030-05351-2_6

crop. However, the cultivation of fahl clover will require extra irrigation water, which could be obtained from changing the prevailing surface irrigation in basins or on narrow furrows to raised beds. Under these circumstances, 20% of the applied water to surface irrigation could be saved (Abouelenein et al. 2010). Ouda and Zohry (2018) stated that implementing cultivation on raised beds for all crops cultivated in the old lands could save about 10.0 billion m^3 of irrigation water.

Another important leguminous summer forge crop that could be used to reduce the gap of summer feed crops is cowpea. Cowpea has the ability to maintain soil fertility through its excellent capacity to fix atmospheric nitrogen, and it does not require very fertile land for growth (Lobato et al. 2006). Cowpea is an important source of protein, phosphorus, minerals, and certain soluble vitamins in human diet (Karigoudar and Angadi 2005) and is equally important as nutritious fodder for livestock (Singh et al. 2003). As a legume fodder, it provides high-quality forage rich in proteins (14–24% dry matter) (Heuzé et al. 2013). Intensive cropping for cowpea, namely intercropping it with several crops as a secondary crop, could increase its cultivated area and attain its positive effect on the yield of the main crop in the cropping systems. Furthermore, no extra irrigation water is needed to be applied to cowpea as secondary crop in the intercropping system because it shares the applied water to the main crop (Zohry and Ouda 2018). Additionally, implementing intercropping systems will increase the productivity of unit land and water.

The impacts of climate change on crop yield could already be detected in observed data (Lobell et al. 2011). Previous national studies on climate change effects on crops concluded that decreasing production (Ibrahim et al. 2012; Ouda et al. 2010, 2013, 2014) and increasing water requirements (Ouda et al. 2016a, b; Mahmoud et al. 2016; Taha et al. 2016) are expected in the future. Thus, we have more than enough information about climate change and variability to understand that it is a serious problem that requires immediate attention (Heal and Millner 2014).

Furthermore, farmers already have to deal with changing weather patterns and rising frequency and intensity of extreme weather events, making farming even more risky (IPCC 2012). Thus, intensive cropping could be both mitigation and adaptation measures to reduce the negative effect of climate change. Cultivation of fahl clover as a third crop between summer and winter crop and cultivation of cowpea intercropping systems with other summer crops, where both increase soil organic matter, could be a strategy for sequestering carbon dioxide to mitigate anthropogenic greenhouse gas emissions (Liu et al. 2014).

Thus, the objective of this chapter was to quantify the effect of using unconventional practices to increase the cultivated area of summer forage crops through: (1) cultivation of fahl clover as an early winter crop after maize, rice, or sorghum crop and before the following winter crop; (2) implementing intercropping systems of cowpea with maize, sunflower, sorghum, and under fruit trees.

The assessment was done using the data of 2015 and the projected data in 2030 in the five agro-climatic zones of Egypt developed by (Ouda and Noreldin 2017) (Fig. 6.1).

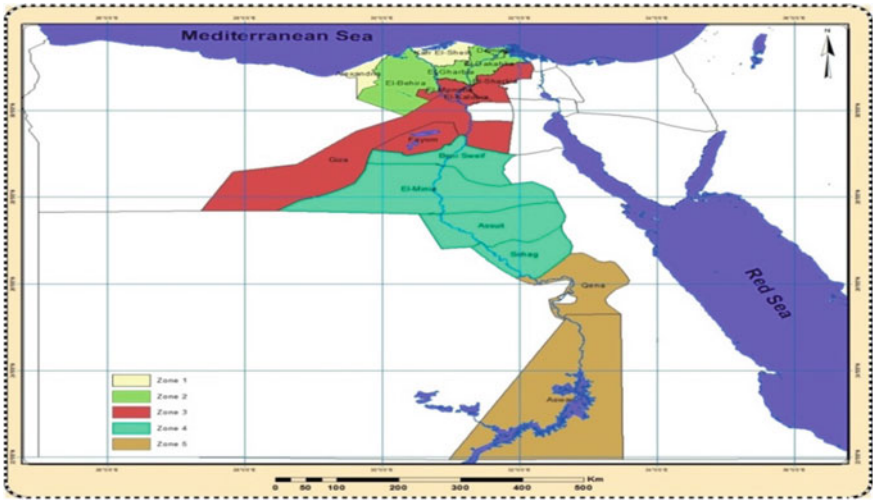

Fig. 6.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

Increasing the Cultivated Area of Fahl Clover and Cowpea

Increasing the Cultivated Area of Fahl Clover

There was no published data by the Ministry of Agriculture and Land Reclamation in Egypt about the cultivated area of fahl clover in 2015, which implied that it is not a very common practice between farmers. Because we suggested increasing its cultivated area by planting it after maize, rice, or sorghum, the cultivated area of these crops on the level of each agro-climatic zone in 2015 was calculated using data published by the Ministry of Agriculture and Land Reclamation in Egypt. The calculation was done for both old lands (clay soils located in the Nile Delta and Valley) and new lands (marginal soils located around the old lands).

Cultivation of Fahl Clover After Maize

Zohry et al. (2017a) compared between the effect of conventional crop sequence, namely wheat then maize and cultivation of three-crop per year, namely maize, fahl clover, then wheat on wheat yield. Their results indicated that wheat productivity was increased by 16 and 47% in the first and second season, respectively, when fahl clover followed maize, compared to the conventional crop sequence. This result attributed to the residual effect of fahl clover cultivated before wheat on increasing available nitrogen, which benefited wheat yield more in the second growing season. Furthermore, inclusion of legumes in a cropping sequence could improve soil quality

(Espinoza et al. 2015), and it could influence specific microorganism populations in the rhizosphere for the benefit of the following crops (McCallum et al. 2004). Zohry et al. (2017a) indicated that wheat water productivity, in the three-crop sequence, was increased by 4 and 63% in the first and second season, respectively, compared to its counterpart value in conventional crops sequence. This is a result of improved in soil structure and soil porosity as indicated by (McCallum et al. 2004).

We suggested that 70% of maize cultivated area to be used to cultivate fahl clover after the occurrence of maize harvest. Table 6.1 presents the potential assigned area in both old and new lands to fahl clover in 2015. The table indicated that the highest potential assigned area of fahl clover could be obtained in the fourth agro-climatic zone in both old and new lands whereas the lowest potential assigned area of fahl clover could be obtained in the fifth agro-climatic zone in the old. In the new lands, the lowest potential area could be obtained in first agro-climatic zone. Thus, 632,374 ha of fahl clover could be obtained as a total on the five agro-climatic zones.

Cultivation of Fahl Clover After Rice

Sheha et al. (2014) reported that cultivation of fahl clover before sugar beet and after rice increase sugar beet yield as a result of nitrogen fixation, which accelerate the microbial activity of the soil. Furthermore, considerable amount of legume crops residue with narrower C/N ratio exist in the soil after harvest these crops, which upon decomposition improves the physical condition and fertility of soil (Pokhrel and Pokhrel 2013).

We suggested that 70% of rice cultivated area to be assigned to cultivate fahl clover after the occurrence of rice harvest. Table 6.2 presents the potential assigned area to be cultivated with fahl clover. The results in Table 6.2 indicated that the highest potential assigned area to fahl clover could be obtained in the second agro-climatic zones in both old and new lands. This practice could add 333,480 ha of fahl clover. It could be noticed from the table that rice is not cultivated the fourth and fifth agro-climatic zone because it is prohibited by the law.

Table 6.1 Maize cultivated area in the old and the new lands, the potential assigned area to fahl clover, and the total area in 2015

	Maize cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	30,658	21,461	5700	3990	25,451
Zone 2	170,062	119,043	8734	6114	125,157
Zone 3	300,686	210,480	12,831	8982	219,462
Zone 4	327,472	229,230	13,165	9216	238,446
Zone 5	25,061	17,543	9023	6316	23,859
Total	853,939	597,757	49,452	34,617	632,374

Table 6.2 Rice cultivated area in the old and the new lands, the potential assigned area to fahl clover and the total area in 2015

	Rice cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	102,139	71,497	1714	1200	72,697
Zone 2	280,003	196,002	4953	3467	199,470
Zone 3	87,548	61,284	43	30	61,314
Zone 4	0	0	0	0	0
Zone 5	0	0	0	0	0
Total	469,970	328,783	6710	4697	333,480

Cultivation of Fahl Clover After Sorghum

Cultivation of fahl clover after sorghum is a common practice on small scale by farmers in Egypt. This practice was lately disseminated by the Central Agency of Agricultural Extension in Egypt.

We suggested that fahl clover will be cultivated after sorghum on 50% of its cultivated area. The results in Table 6.3 presented the potential assigned area to be cultivated with fahl clover. The table indicated that the highest potential assigned area to fahl clover could be obtained in the fourth agro-climatic zones in both old and new lands. Thus, 73,761 ha could be added to fahl clover cultivated area. It could be noticed from the table that sorghum is only calculated in the third, fourth, and fifth agro-climatic zones, as a result of more suitable weather conditions.

Total Potential Area of Fahl Clover

Table 6.4 presents the total potential area of fahl clover resulted from cultivating it after maize, rice, and sorghum. The table showed that the fourth agro-climatic zone

Table 6.3 Sorghum cultivated area in the old and the new lands, the potential assigned area to fahl clover, and the total area in 2015

	Sorghum cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	0	0	0	0	0
Zone 2	0	0	0	0	0
Zone 3	49,299	24,650	463	231	24,881
Zone 4	72,682	36,341	7728	3864	40,205
Zone 5	14,308	7154	3044	1522	8676
Total	136,288	68,144	11,235	5,617	73,761

Table 6.4 Total potential cultivated area of fahl clover in the agro-climatic zones of Egypt and its water requirements in 2015

	Maize (ha)	Rice (ha)	Sorghum (ha)	Total area (ha)	Total water requirements (m^3)
Zone 1	25,451	72,697	0	98,147	188,322,133
Zone 2	125,157	199,470	0	324,627	651,306,072
Zone 3	219,462	61,314	24,881	305,656	667,552,704
Zone 4	238,446	0	40,205	278,651	700,249,963
Zone 5	23,859	0	8676	32,534	92,233,890
Total	632,374	333,480	73,761	1,039,616	2,299,664,762

will have the highest total area of fahl clover. The total potential cultivated area will reach 1,039,616 ha.

Water requirement for fahl clover on the level of each agro-climatic zone was calculated, as well as total water requirements. Table 6.4 indicates that the potential areas of fahl clover need the application of 2,299,664,762 m^3 of irrigation water. This amount could be obtained if cultivation on raised beds was implemented on the national level in the old lands of Egypt.

Increasing the Cultivated Area of Cowpea

The cultivated area of cowpea could be increased by intercropping it as the secondary crop with maize, sunflower, and sorghum, as well as under young fruit trees. To quantify the effect of intercropping systems with cowpea, the cultivated area of these crops was collected in 2015 on the level of each agro-climatic zone. It was found that cowpea was only cultivated in the fifth agro-climatic zone and its area was 516 ha in 2015.

In each of these suggested intercropping systems, we assumed that cowpea is cultivated in 50% of its recommended planting density, as it was stated in the literature. This percentage was taking into consideration in the calculation process, so that the added potential cultivated area as a result of intensive cropping will give a yield per hectare not the percentage of cultivated seeds.

Cowpea Intercropped with Maize

Cowpea intercropped with maize system (Fig. 6.2) resulted in an increase in maize yield by 10% (Hamd-Alla et al. 2014) and a reduction in maize-associated weeds (Zohry 2005). Intercropping legume crop with cereal crop has many benefits. Dahmardeh et al. (2010) stated that in intercropping legume with cereals, legumes

Fig. 6.2 Maize intercropped with cowpea system

fix atmospheric nitrogen, which may be utilized by the host plant or may be excreted from the nodules into the soil and be used by other plants growing nearby. A detailed description on how to implement this system is provided in Chap. 3.

Table 6.5 presents the total cultivated area of maize and the potential area to be assigned to cowpea intercropped with maize system. The table indicated that the highest cultivated area of cowpea could be obtained in the fourth agro-climatic zone in both old and new lands. This cowpea intercropping system will increase its cultivated area by 225,848 ha.

Table 6.5 Maize cultivated areas in the old and the new lands, the potential assigned area to cowpea intercropping system and the total area in 2015

	Maize cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	30,658	7665	5700	1425	9089
Zone 2	170,062	42,516	8734	2184	44,699
Zone 3	300,686	75,171	12,831	3208	78,379
Zone 4	327,472	81,868	13,165	3291	85,159
Zone 5	25,061	6265	9023	2256	8521
Total	853,939	213,485	49,452	12,363	225,848

Cowpea Intercropped with Sunflower in 2015

Zohry et al. (2017b) stated that cowpea intercropped with sunflower did not significantly affect sunflower yield because of the high competitiveness of sunflower, as a tall crop versus cowpea as short foliage plant. Amujoyegbe et al. (2013) indicated that intercropping cowpea with sunflower did not affect sunflower yield, but it increases land equivalent ratio to be 200%. Rodrigues (2011) stated that, in cowpea intercropping with sunflower system, the highest productivity of sunflower occurred when cowpea planting density was 25%. Sunflower planting density under this system is 100%, and cowpea planting density is 50% of its recommended density.

Table 6.6 presents the potential assigned area of cowpea to be intercropped with sunflower. The table showed that the second agro-climatic zone will provide the highest area of cowpea in the old lands. Similarly, in the new lands, the third agro-climatic zone will provide the highest area. The total area of cowpea that could be provided by intercropping it with sunflower is 2228 ha.

Cowpea Intercropped with Sorghum

Abou-Keriasha et al. (2011) indicated that cowpea intercropped with sorghum system (Fig. 6.3) resulted in sorghum yield increase by 8%, compared to sole sorghum planting. Furthermore, associated weeds with sorghum were decreased by 81%, compared to sole planting. Sorghum planting density under this system is 100%, and cowpea planting density was 50% of its recommended density.

Table 6.7 presents the cultivated area of sorghum in both old and new lands and the potential assigned area to cowpea intercropping system.

The highest assigned area for cowpea could be found in the fourth agro-climatic zone in both old and new lands. This practice could add 36,881 ha to the cultivated area of cowpea.

Table 6.6 Sunflower cultivated areas in the old and the new lands, the potential assigned area to cowpea intercropping system and the total area in 2015

	Sunflower cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	63	16	173	43	59
Zone 2	2605	651	1043	261	912
Zone 3	1690	423	1251	313	735
Zone 4	1901	475	188	47	522
Zone 5	0	0	0	0	0
Total	6260	1565	2654	664	2228

Fig. 6.3 Cowpea intercropped with sorghum system

Table 6.7 Sorghum cultivated area in the old and the new lands, the potential assigned area to cowpea intercropping system and the total area in 2015

	Sorghum cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	0	0	0	0	0
Zone 2	0	0	0	0	0
Zone 3	49,299	12,325	463	116	12,440
Zone 4	72,682	18,170	7728	1932	20,103
Zone 5	14,308	3577	3044	761	4338
Total	136,288	34,072	11,235	2809	36,881

Cowpea Intercropped Under Young Fruit Trees in 2015

Cowpea could be intercropped under young fruit trees. El-Mehy and El-Badawy (2017) indicated that intercropping cowpea under Washington navel orange trees increased available N, P, and K content in the soil and resulted in more effective weeds suppression. Furthermore, this system resulted in improving fruit yield and quality, compared to monoculture of orange tree. Tiwari and Baghel (2014) reported that intercropping cowpea under mango trees was beneficial, where mango yield and fruit quality was improved. Moreover, nitrogen concentration in the soil was improved due to the cultivation of cowpea.

Table 6.8 shows that the area that could be assigned to cowpea intercropped under fruit trees was the highest in the third agro-climatic zone in both old and new lands. This system could increase cowpea cultivated area by 80,022 ha on the national level.

Table 6.8 Fruit trees cultivated area in the old and the new lands, the potential assigned area to cowpea intercropping system, and the total area in 2015

	Old lands (ha)	Assigned area (ha)	New Lands (ha)	Assigned area (ha)	Total area (ha)
Zone 1	4860	1215	1770	443	1658
Zone 2	49,715	12,429	39946	9987	22,415
Zone 3	99,566	24,891	73890	18,473	43,364
Zone 4	28,353	7088	8987	2247	9335
Zone 5	10,323	2581	2680	670	3251
Total	192,816	48,204	127,274	31,818	80,022

Total Potential Area of Cowpea

Table 6.9 presents the total potential area of cowpea resulted from intercropping it with maize, sunflower, sorghum and under fruit trees. The table showed that the third agro-climatic zone will have the highest area of cowpea. The potential total area of cowpea will reach 342,687 ha with 66212% increase than its cultivated area in 2015. This extra cultivated area will not require the application of extra irrigation water because cowpea will get its required water from the applied water to the main crop in the intercropping system.

The Potential Total Added Area of Summer Forge

Table 6.10 presents the total potential increase in summer forage cultivated area as a result of fahl clover cultivation and intercropping systems of cowpea with other crops. The results in the table indicated that the third agro-climatic zone could have the highest cultivated area of suggested summer forage crops whereas the lowest cultivated area of suggested summer forage crops could be found in the fifth agro-climatic zones. The recorded value of the total area of summer forage crops by The

Table 6.9 Total potential cultivated area of cowpea in the agro-climatic zones of Egypt in 2015

	Cowpea (ha)	Maize (ha)	Sunflower (ha)	Sorghum (ha)	Fruit trees (ha)	Total area (ha)
Zone 1	0	9089	59	0	1658	10,806
Zone 2	0	44,699	912	0	22,415	68,026
Zone 3	0	78,379	735	12,325	43,364	134,803
Zone 4	0	85,159	522	18,170	9335	113,187
Zone 5	516	8521	0	3577	3251	15,864
Total	516	225,848	2228	34,072	80,022	342,687

Table 6.10 Total potential cultivated area of fahl clover and cowpea in the five agro-climatic zones of Egypt in 2015

	Area of fahl clover (ha)	Area of cowpea(ha)	Total area (ha)
Zone 1	98,147	10,806	108,953
Zone 2	324,627	68,026	392,653
Zone 3	305,656	134,803	440,459
Zone 4	278,651	113,187	391,838
Zone 5	32,534	15,864	48,398
Total	1,039,615	342,686	1,382,301

Ministry of Agriculture and Land Reclamation in 2015 was 88,235 ha. Thus, the total potential increase in this area is expected to be 1,382,301 ha, which will increase the area of summer forage crops by 1467%, compared to the recorded value in 2015.

The Projected Cultivated Areas of the Studied Crops in 2030

Previous studies on the effect of climate change on evapotranspiration (Ouda et al. 2016) and water requirements for several crops in Egypt (Zohry and Ouda 2016a, b) projected a rise in the values of evapotranspiration and water requirements for the cultivated crops. These studies also projected reduction in the cultivated area of these crops as a result of limited water resources in Egypt. Thus, reduction in the cultivated area of the studied crops, namely fahl clover, cowpea, maize, sunflower, sorghum, and young fruit trees in each agro-climatic zone in Egypt was calculated.

To assess the effect of climate change on water requirements of the studied crops, climate change scenario RCP6.0 resulted from MIROC5 climate change model in 2030 was used in this analysis. The model is available from the following website: http://www.ccafs.cgiar.org/marksimgcm#.Ujh1gj-GfMY. The MIROC5 model is one on the CMIP5 General Circulation Models developed by Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology. The model has a horizontal resolution equal to 1.40º × 1.40º.

RCP6.0 climate change scenario is one of the four RCPs scenarios produced by MIROC5 model to represent a larger set of mitigation scenarios and have different targets in terms of radiative forcing in 2100. The scenario is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions (Fujino et al. 2006; Hijioka et al. 2008).

The calculated values of water requirements using RCP6.0 climate change scenario were compared to its counterpart values calculated in 2015. Percentage of increase in water requirements for the selected crops and percentage of reduction in the cultivated area in the five agro-climatic zones of Egypt in 2030 is presented in Table 6.11.

The Projected Cultivated Area of Fahl Clover in 2030

Regarding projected fahl clover cultivated area after maize in 2030; Table 6.12 shows that the total projected fahl clover area will be reduced to 569,058 ha, with 10% reduction, compared to its counterpart in 2015.

With respect to projected fahl clover cultivated area after rice in 2030, Table 6.13 indicates that the projected fahl clover area will be reduced by 7% to be 309,252 ha, compared to its counterpart in 2015.

Similarly, the projected fahl clover cultivated area after sorghum in 2030 will be reduced to 65,434 ha, with 11% reduction compared to its counterpart in 2015 (Table 6.14).

Table 6.15 presents the projected total cultivated area of fahl clover as a result of cultivating it after maize, rice, and sorghum in 2030. The projected area will be 943,744 ha, with 9% decrease, compared to its counterpart value in 2015. This area will need 2,255,559,005 m^3 of irrigation water, which could be obtained from changing cultivation method to raised beds to save 20% of the applied water to surface irrigation system.

Projected Cultivated Area of Cowpea in 2030

With respect to the projected cowpea cultivated area as a result of intercropping it with maize in 2030, Table 6.16 indicates that the projected cowpea area will be reduced by 10% to reach 203,235 ha, compared to its counterpart value in 2015.

The projected cultivated area of cowpea in 2030 resulted from intercropping it with sunflower is expected to decrease by 11% to be 1985 ha, compared to its counterpart value in 2015 (Table 6.17).

Similar to sunflower, the projected percentage of reduction in the cultivated area of cowpea under intercropping it with sorghum in 2030 is expected to be 11%, where cowpea cultivated area will be reduced to 32,717 ha (Table 6.18).

Regarding the projected cowpea cultivated area as a result of intercropping it under fruit trees, it is expected to be reduced by 13%, where cowpea total cultivated area will reach 69,437 ha (Table 6.19).

Table 6.20 presents the total projected area of cowpea in 2030 as a result of implementing intercropping systems, where it will be 307,823 ha with 10% reduction, compared to its counterpart value in 2015.

Table 6.11 Percentage of increase in water requirements (WR %) of the selected crops and percentage of reduction in the cultivated area (CA %) in the agro-climatic zones of Egypt in 2030

	Fahl clover		Cowpea		Maize		Sunflower		Sorghum		Fruit trees	
	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)
Zone 1	8	8	4	4	2	2	4	4	NC	NC	3	3
Zone 2	9	9	9	8	7	7	8	7	NC	NC	10	9
Zone 3	9	9	14	12	15	13	14	12	15	13	18	15
Zone 4	10	10	18	17	17	15	20	17	17	15	19	16
Zone 5	11	11	19	18	21	17	NC	NC	21	17	19	16
Average	9	9	13	12	12	11	12	10	18	15	14	12

NC not cultivated

Table 6.12 Projected maize cultivated areas in old and new lands, the potential assigned area of fahl clover, and the total area in 2030

	Maize cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	30,045	21,031	5586	3910	24,942
Zone 2	158,158	110,710	8123	5686	116,396
Zone 3	261,597	183,118	11,163	7814	190,932
Zone 4	298,000	208,600	11,980	8386	216,986
Zone 5	20,801	14,560	7489	5242	19,803
Total	768,599	538,020	44,341	31,039	569,058

Table 6.13 Projected rice cultivated area in the old and the new lands, the potential assigned area of fahl clover, and the total area in 2030

	Rice cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	98,053	68,637	1645	1152	69,789
Zone 2	260,403	182,282	4606	3224	185,506
Zone 3	77,042	53,930	38	26	53,956
Zone 4	0	0	0	0	0
Zone 5	0	0	0	0	0
Total	435,498	304,849	6290	4403	309,252

Table 6.14 Projected sorghum cultivated area in the old and the new lands, the potential assigned area of fahl clover and the total area in 2030

	Sorghum cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	0	0	0	0	0
Zone 2	0	0	0	0	0
Zone 3	42,890	21,445	403	201	21,646
Zone 4	66,141	33,070	7032	3516	36,587
Zone 5	11,876	5938	2527	1263	7201
Total	120,906	60,453	9962	4981	65,434

The Potential Total Added Area of Summer Forage in 2030

Table 6.21 presents total potential increase in summer forage cultivated area as a result of fahl clover cultivation and intercropping cowpea with other crops in 2030. The results in the table indicated that the cultivated area of summer forage crops is expected to be 1,251,567 ha, which is 9% less than its counterpart value in 2015.

Table 6.15 Projected total cultivated area of fahl clover in the agro-climatic zones of Egypt in 2030

	Maize (ha)	Rice (ha)	Sorghum (ha)	Total area (ha)	Total water requirements (m^3)
Zone 1	24,942	69,789	0	94,731	196,945,342
Zone 2	116,396	185,506	0	301,903	661,468,491
Zone 3	190,932	53,956	21,646	266,534	632,486,081
Zone 4	216,986	0	36,587	253,572	683,377,400
Zone 5	19,803	0	7201	27,004	81,281,691
Total	569,058	309,252	65,434	943,744	2,255,559,005

Table 6.16 Projected cowpea cultivated area in the old and the new lands, the potential assigned area of cowpea intercropping system with maize and the total area in 2030

	Cowpea cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	30,045	7511	5586	1397	8908
Zone 2	158,158	39,539	8123	2031	41,570
Zone 3	261,597	65,399	11,163	2791	68,190
Zone 4	298,000	74,500	11,980	2995	77,495
Zone 5	20,801	5200	7489	1872	7072
Total	768,599	192,150	44,341	11,085	203,235

Table 6.17 Projected cowpea cultivated area in the old and the new lands, the potential assigned area of cowpea intercropping system with sunflower and the total area in 2030

	Cowpea cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	60	15	166	42	57
Zone 2	2423	606	970	242	848
Zone 3	1487	372	1101	275	647
Zone 4	1578	394	156	39	433
Zone 5	0	0	0	0	0
Total	5548	1387	2393	598	1985

Crop Rotations in Egypt

Sharq El-Owainat are located in the Sahara Desert, southwest Egypt. The region lies approximately 290 km from the nearest city and 210 km from the Toshka lakes. A large agricultural project was implemented in this region, where the Nubian Sandstone Aquifer is the only source for irrigation. The soil of this region is sandy with low fertility.

Two-year and three-year crop rotations were implemented in Sharq El-Owainat. It started with the summer season of 2004 until the winter season of 2006/07 to produce

Table 6.18 Projected cowpea cultivated area in the old and the new lands, the potential assigned area of cowpea intercropping system with sorghum and the total area in 2030

	Cowpea cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	0	0	0	0	0
Zone 2	0	0	0	0	0
Zone 3	42,890	10,723	403	101	10,823
Zone 4	66,141	16,535	7032	1758	18,293
Zone 5	11,876	2969	2527	632	3601
Total	120,906	30,227	9962	2490	32,717

Table 6.19 Projected cowpea cultivated area in the old and the new lands, the potential assigned area of cowpea intercropping system under fruit trees and the total area in 2030

	Cowpea cultivate area (ha) in				
	Old lands	Assigned area	New lands	Assigned area	Total area
Zone 1	4714	1179	1717	429	1608
Zone 2	45,241	11,310	36,351	9088	20,398
Zone 3	84,631	21,158	62,807	15,702	36,859
Zone 4	23,817	5954	7549	1887	7841
Zone 5	8671	2168	2251.2	563	2731
Total	167,074	41,768	110,675	27,669	69,437

Table 6.20 Total projected cultivated area of cowpea in the agro-climatic zones of Egypt in 2030

	Cowpea (ha)	Maize (ha)	Sunflower (ha)	Sorghum (ha)	Fruit trees (ha)	Total area (ha)
Zone 1	0	8908	57	0	1608	10,572
Zone 2	0	41,570	848	0	20,398	62,816
Zone 3	0	68,190	647	10,823	36,859	116,520
Zone 4	0	77,495	433	18,293	7841	104,063
Zone 5	449	7072	0	3601	2731	13,853
Total	449	203,235	1985	32,717	69,437	307,823

Table 6.21 Total potential cultivated area of fahl clover and cowpea in the five agro-climatic zones of Egypt in 2015

	Area of fahl clover (ha)	Area of cowpea (ha)	Total area (ha)
Zone 1	94,731	10,572	105,303
Zone 2	301,903	62,816	364,719
Zone 3	266,534	116,520	383,054
Zone 4	253,572	104,063	357,635
Zone 5	27,004	13,853	40,856
Total	943,744	307,823	1,251,567

Fig. 6.4 Implemented two-year forage crop rotation in Sharq El-Owainat, Egypt

Year 1	Year 2
Soybean Maize (silage) Fodder beet	Sunflower Clover
Sunflower Clover	Soybean Maize (silage) Fodder beet

forage crops. Sprinkler system was the used system to deliver water to the cultivated crops. The aim of implementing these crop rotations in this region was to improve the fertility of the soil by application of organic manure as the only source of applied fertilizers. Additionally, to encourage investment in production of animals meats in this region.

With respect of the two-year crop rotation (Fig. 6.4), it contained 66% forage crops (maize (silage), fodder beet, and clover) distributed between summer and winter seasons. In the first section of the rotation, soybean, which is a legume crop, was cultivated to improve soil properties. In addition, soybean and sunflower are important crops for edible oil production.

In the second section of the rotation, the yield of maize (silage) was increased from 36 ton/ha in the first year of the rotation to 48 ton/ha in the second year of the rotation, with 33% increase. This increase was attributed to the cultivation of soybean before it, and to the crop rotation effects, as well. The yield of above-ground biomass fodder beet was increased by 13% from 96 ton/ha in the first year of the rotation to 108 ton/ha in the second year of the rotation. In addition, the tuber yield of sugar beet was increased by 12% from 120 ton/ha in the first year of the rotation to 134 ton/ha in the second year of the rotation. However, clover yield was reduced by 12% as a result of the cultivation of sunflower (a soil exhausting crop) before it.

Figure 6.5 presents the three-year crop rotation implemented in Sharq El-Owainat. The rotation contained 75% forage crops, namely maize (silage), fodder beet, cowpea, and clover distributed between summer and winter seasons. In the third year of the rotation, the yield of maize (silage) was 43.2 ton/ha, compared to 40.8 ton/ha in the first year of the rotation, with 6% increase. Furthermore, fodder beet yield was increased to 194.4 ton/ha in the third year of the rotation, compared to 168.0 ton/ha in the first year of the rotation, with 16% increase. With respect to cowpea, its yield was 220.8 ton/ha in the third year, compared to 196.8 ton/ha in the first year, with 12% increase. The yield of clover was increased by 7% from 280.8 ton/ha in the first year to 300.0 ton/ha in the third year of the rotation. Sunflower yield was increased by 9% from 2.76 ton/ha in the first year to 3.0 ton/ha in the third year of the rotation. Similarly, clover yield was increased by 4% from 292.8 ton/ha in the first year to 304.8 ton/ha in the third year of the rotation. This higher percentage of increase in clover yield in the second section of the rotation, compared to its counterpart in the third section was attributed to cultivation of cowpea before it.

Year 1	Year 2	Year 3
Maize (silage) Fodder beet	Cowpea Clover	Sunflower Clover
Cowpea Clover	Sunflower Clover	Maize (silage) Fodder beet
Sunflower Clover	Maize (silage) Fodder beet	Cowpea Clover

Fig. 6.5 Implemented three-year forage crop rotation in Sharq El-Owainat, Egypt

Year 1	Year 2	Year 3
Fodder beat Cowpea intercropped with maize	Faba bean Maize (silage) Fahl clover	Clover Sorghum (forage)
Faba bean Maize (silage) Fahl clover	Clover Sorghum (forage)	Wheat Cowpea
Clover Sorghum (forage) Fahl clover	Wheat Cowpea	Faba bean Maize (silage) Fahl clover

Fig. 6.6 Suggested three-year forage crops rotation in the marginal lands of Egypt

It worth noting that the productivities of the cultivated crops in these rotations were higher than its counterpart value produced in the fifth agro-climatic zone. This could be attributed to the distribution of the crops within the rotation, in addition to the application of organic manure.

Suggested Forage Crop Rotation in the New Lands of Egypt

One way of increasing the production of winter and summer forage crops in Egypt is to expand its cultivation in the marginal lands of sandy soil surrounding the Nile Delta and Valley. A suggested crop rotation could be implemented contained 90% forage crops (Fig. 6.6).

Conclusion

Animal production is suffering from scarcity of summer feed because of the competition maize and rice in one side and the other forage summer crop on the other side. Using the unconventional practices, the cultivated area of two important feed crops could be increased to fill the gap between production and consumption of summer feed crops. These two crops are fahl clover and cowpea, where its cultivated area could be increased by 1467%, compared to its value in 2015, if the suggested unconventional practices were implemented. This large percentage of increase will generally contribute in reducing the competition between the production of human food and animal feed in Egypt. Furthermore, the projected area of these two crops in 2030 under climate change is expected to be reduced by only 9%, which will still provide high contribution in filling the projected gap of summer feed.

The rotational effect on its cultivated crops was observed in the studied two-year and three-year crop rotations implemented in Sharq El-Owainat region, where the yield of the cultivated crops was increased in the last year of the rotation, compared the first year. Furthermore, these crop rotations could be implemented in the marginal lands of Egypt to increase the yield of forage crops and reduce its production-consumption gap. Expansion in the newly reclaimed lands in Egypt to cultivate more winter, and summer feed crops could also contribute in increasing the production of livestock on the national level. This should be encouraged by the government of Egypt to reduce the gap of red meat in Egypt.

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Chapter 7
Crop Rotation and Edible Oil Production–Consumption Gap in Egypt

Introduction

Edible oils are a major constituent of human food. Cotton seeds, soybean, sunflower, maize embryos, and flax seeds are the major sources of edible oil in Egypt. Edible oils group comes in second place after wheat, with respect to importation (Hassan and Sahfique 2010). In 2011, Egypt imported 350,101 tons of soybean oil, 262,764 tons of sunflower oil, and 509,060 tons of palm oil to fulfill the needs of the Egyptian population (http://egypt.opendataforafrica.org/FAOTS2013Sep/trade-statistics-crops-livestock%20products-liveanimal-2013). Egypt used to be self-sufficient in edible oils, where self-sufficiency ratio reached 95%. Such ratio followed a declining trend reaching 32% in 2007 (Hassan and Sahfique 2010). According to the Ministry of Agriculture and Land Reclamation in Egypt, the current edible oil production—consumption gap is estimated by 97%. This huge decline could be mainly attributed to the growing population in the recent years. The Egyptian population size increased almost by more than 1.5 times during the last three decades, between 1986 and 2013, from about 48 million to about 85 million in 2013 (CAPMAS 2014).

IPCC (2007) stated that "climate change is one of the overwhelming environmental threats that are defined as a long-term alteration in the global weather patterns, including temperature, precipitation, soil moisture, sea level, and storm activity". In addition, the projected climatic changes will be among the most important challenges for agriculture in the twenty-first century, especially for developing countries and arid regions (IPCC 2013). Accordingly, it is expected that climate change will induce disruption in food production systems in Egypt. Furthermore, Alkitkat (2017) indicated that, in 2030, the Egyptian population size is expected to reach about 126 million inhabitants, which will put more pressure on food production. Thus, increasing the efficiency of using our natural resources, namely soil, water, and weather resources could increase food production and availability, as well as reduce food insecurity.

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Intensive cropping could fully utilize available water and labor when arable land is limited. Intensive cropping could be divided to intercropping systems and successive cropping. An intercropping system is two or more crops share the same piece of land for part of its growing season (relay intercropping), or share all its growing season (Adigbo et al. 2013). On the other hand, Gallaher (2009) defined successive cropping as two or more crops grown in succession on the same land per year. These forms are generally known as double cropping, triple cropping, and quadruple cropping. In Egypt, it is very common to implement double cropping and it is possible to implement triple cropping. In fact, triple cropping proved to improve soil fertility and increase farmer net income (Zohry et al. 2017a, b; Sheha et al. 2014). Intensive cropping was previously implemented on farm level in many parts of Egypt (Mohamed et al. 2013; Abou-Elela 2012; Ibrahim et al. 2010; Zohry and Ouda 2016; Zohry et al. 2017a, b), and it could be used to increase the cultivated area of edible oil crops. Furthermore, the gap between production and consumption of edible oil could be reduced using intensive cropping under present conditions and in the future in 2030 under climate change.

Thus, the objective of this chapter was to quantify the effect of using intensive cropping on increasing the cultivated area of selected edible oil crops using data published in 2015 and projected data in 2030 in the five agro-climatic zones of Egypt. Figure 7.1 shows the five agro-climatic zones developed by Ouda and Noreldin (2017).

Collected Data

Five crops produce edible oil were selected, namely cotton, soybean, sunflower, maize, and flax. The cultivated area of each crop on the level of each agro-climatic zone in 2015 was calculated using data published by the Ministry of Agriculture and Land Reclamation in Egypt. Furthermore, to quantify the effect of intercropping systems with the selected oil crops, the cultivated area of wheat, faba bean, winter onion, sugar beet, summer tomato, peanut, sorghum, sugarcane, and young fruit trees was collected on the level of each agro-climatic zone.

Effect of Intensive Cropping on the Cultivated Area of the Selected Oil Crops

Several intercropping systems were suggested to be implemented to increase the cultivated area of the selected oil crops. In each of these intercropping systems, the companion crop (oil crop) is cultivated in different percentage of its recommended

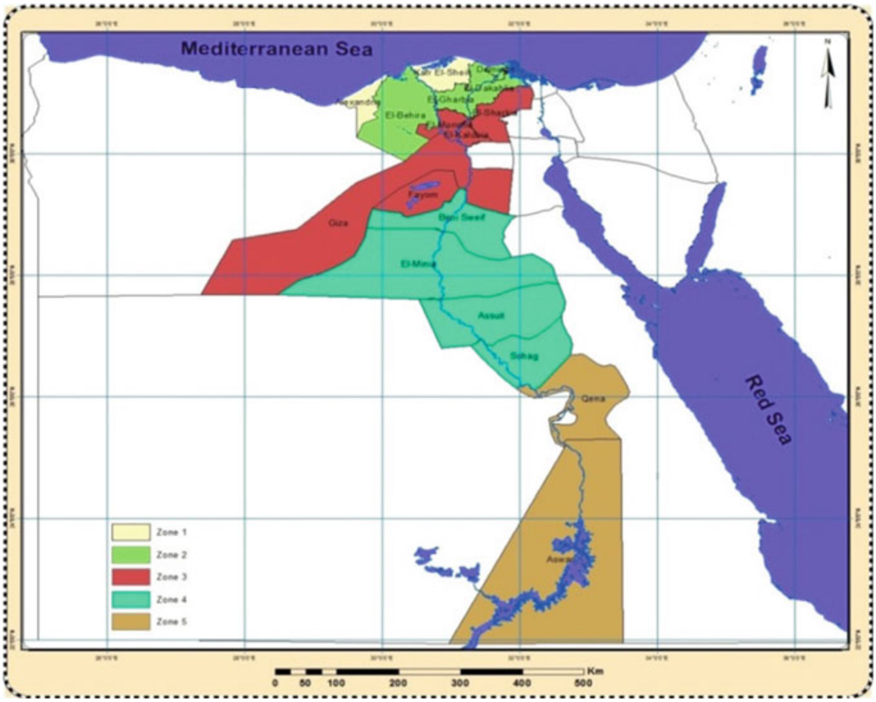

Fig. 7.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

planting density. This percentage was taking into consideration in the calculation process, so that the added potential cultivated area, as a result of intensive cropping will give a yield per hectare not the percentage of cultivated seeds.

Cotton Intercropping Systems

Relay Intercropping Cotton with Wheat System

In relay intercropping cotton on wheat (Fig. 7.2), cotton shares its last two irrigation events with wheat (Zohry 2005). Zhang et al. (2008) stated that in this system, wheat and cotton used more nitrogen per unit production than mono-crops, which can reduce environmental risks of nitrogen leaching to ground water. The system is explained in details in Chap. 3.

We suggested that 20% of the total cultivated area of wheat in each agro-climatic zone level will be assigned to this intercropping system.

Fig. 7.2 Cotton relay intercropped with wheat system

Relay Intercropping Cotton with Onion System

Another successful intercropping system with cotton is relay intercropping it with onion (Fig. 7.3). It attains the same benefits that relay intercropping cotton with wheat does (Zohry 2005). The system is also explained in details in Chap. 3.

Fig. 7.3 Cotton relay intercropped with onion system

Table 7.1 Potential added area to the actual cultivated area of cotton as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2015

	Actual cultivated area (ha)	Added area (ha) under relay intercropping on		Total area (ha)
		Wheat	Onion	
Zone 1	31,381	21,629	14,522	67,532
Zone 2	43,829	64,764	39,103	147,696
Zone 3	22,105	71,435	25,060	118,600
Zone 4	3033	61,793	18,774	83,600
Zone 5	0	0	0	0
Total	100,348	219,621	97,459	417,428

Of the total cultivated area of onion in each agro-climatic zone level, 80% was suggested to be assigned to this intercropping system.

Table 7.1 indicates that the total cultivated area of cotton could be increased from 100,349 to 417,427 ha after implementing the intercropping systems, with 316% increase on the national level. This expected increase will occur in the first agro-climatic zone to the fourth agro-climatic zone because cotton was not cultivated in the fifth agro-climatic zone.

Soybean Intensive Cropping Systems

Soybean Intercropped with Maize System

Soybean intercropped with maize system (Fig. 7.4) can be implemented to increase the cultivated area of soybean (Sherif and Gendy 2012). In this system, maize plants take its water requirements from the applied water to soybean. Intercropping legume crop with a cereal crop increase soil organic content and available nitrogen fixed by legume (Megawer et al. 2010). More details on this system presents in Chap. 3.

We suggested that 20% of the total cultivated area of maize in each agro-climatic zone level will be assigned to this intercropping system.

Soybean Intercropped with Sorghum System

Intercropping legume with cereals is very successful intercropping systems, where improvement in soil fertility occurs. Arshad and Ranamukhaarachchi (2012) indicated that when soybean intercropped with sorghum, sorghum yield was increased, compared to its sole planting. Similar results were obtained in Egypt by

Fig. 7.4 Maize intercropped with soybean system

Abou-Keriasha et al. (1993) when soybean was intercropping with sorghum. They also stated that planting density of both soybean and sorghum under this system was 50% of its recommended density.

We suggested that 20% of the total cultivated area of sorghum in each agro-climatic zone level will be assigned to this intercropping system.

Soybean Intercropped with Sugarcane System

Since nitrogen fertilizer is a substantial cost component of sugarcane cropping system, the use of soybean as intercropped crop plays a considerable role in reduction of production costs. Intercropping soybean (50% of its recommended planting density) with spring sugarcane (Fig. 7.5) increased sugarcane yield, as well as land productivity (Eweida et al. 1996).

We suggested that 10% of the total cultivated area of sugarcane in each agro-climatic zone level will be assigned to this intercropping system.

Soybean Intercropped Under Young Fruit Trees System

Fruit trees provide good environment for intercropping, especially young evergreen fruit tree (1–3 years old) or deciduous fruit trees (Fig. 7.6). Soybean planting density under this system is 50% of its recommended density. El-Mehy and El-Badawy

Fig. 7.5 Soybean intercropped with sugarcane system

Fig. 7.6 Soybean intercropped under apple trees

(2017) indicated that intercropping soybean under orange trees increased orange yield. Gao et al. (2013) indicated that intercropping soybean under apple trees in China had many benefits on increasing the final yield.

We suggested that 30% of the total cultivated area of fruit trees in each agro-climatic zone will be assigned to this intercropping system.

Relay Intercropping Soybean with Wheat System

Relay intercropping soybean with wheat could be implemented to increase the cultivated area of soybean. This system was known to solve a problem of late sowing for soybean in the USA, where soybean is sown in standing wheat (Nelson et al. 2010). Qayyum et al. (2013) indicated that this intercropping system reduced associated weeds in field and increase wheat yield.

In this system, wheat is cultivated in November on the top of raised beds in four rows and soybean is cultivated in March on both sides of the raised beds. Wheat is harvested in May, and soybean continues to grow until end of June. Soybean planting density under this system is 50% of its recommended density.

We suggested using 10% of the cultivated area with wheat to implement this system.

Table 7.2 indicates that the total cultivated area of soybean under intercropping systems could be increased from 14,130 to 338,433 ha on the national level. This expected increase will occur in the first agro-climatic zone to the fourth agro-climatic zone because soybean was not cultivated in the fifth agro-climatic zone.

Cultivation of Soybean as an Early Summer Crop System

Soybean could be cultivated as early summer crop after early sugar beet and faba bean. In this case of early sugar beet, it is cultivated between end of September and beginning of October and harvested in March. Then, soybean could be cultivated and harvested in June, where another summer crop could be cultivated after it.

We suggested using 30% of early sugar beet cultivated area to be assigned to soybean cultivation, with 100% of its recommended density.

Similarly, early soybean could be cultivated after faba bean, where faba bean is usually harvested in March. We suggested using 40% of faba bean cultivated area to be assigned to soybean cultivation, with 100% planting density.

Table 7.2 Potential added area to the actual cultivated area of soybean as a result of implementing intensive systems in the agro-climatic zones of Egypt in 2015

	Actual cultivated area (ha)	Added area under intercropping soybean with (ha)					Total area (ha)
		Maize	Sorghum	Sugarcane	Fruit trees	Relay on wheat	
Zone 1	430	3636	0	0	1602	10,815	16,482
Zone 2	847	21,373	0	0	57,003	32,382	111,606
Zone 3	125	31,352	4976	0	41,046	35,717	113,216
Zone 4	12,728	34,064	8041	1038	10,361	30,896	97,128
Zone 5	0	0	0	0	0	0	0
Total	14,130	90,425	13,017	1038	110,013	109,810	338,433

Table 7.3 Potential added area to the actual cultivated area of soybean as a result of early cultivation in the agro-climatic zones of Egypt

	Actual area (ha)	Added area of soybean after (ha)		Total area (ha)
		Sugar beet	Faba bean	
Zone 1	430	19,534	2279	22,243
Zone 2	847	16,660	3200	20,707
Zone 3	125	10,266	1548	11,939
Zone 4	12,728	6494	734	19,956
Zone 5	0	0	0	0
Total	14,130	52,954	7761	74,845

The results in Table 7.3 indicated that using early cultivation for soybean could increase its cultivated area by extra 74,844 ha.

Sunflower Intensive Cropping Systems

Sunflower Intercropped with Summer Tomato System

With respect to sunflower intercropped with tomato, Abdel (2006) indicated that intercropping sunflower with tomato resulted in mitigating heat stress through evaporative cooling and shading means, which improved fruit set and consequently yield quality. Furthermore, Kestha and El-Baz (2004) stated that this system could modify the microclimate for tomato, where it protected the tomato fruits from sun damage in July and August. Sunflower planting density under this system is 60% of its recommended density.

We suggested that 40% of the total cultivated area of tomato in each agro-climatic zone will be assigned to this intercropping system.

Sunflower Intercropped with Sugarcane System

El-Gergawi et al. (2000) indicated that land productivity was increased when sunflower was intercropped with spring sugarcane. Under this system sugarcane planted in March and in April, sunflower could be cultivated on one row and harvest in July (Fig. 7.7). Sunflower planting density under this system is 50% of its recommended density.

We suggested that 10% of the total cultivated area of sugarcane in each agro-climatic zone will be assigned to this intercropping system.

Fig. 7.7 Sunflower intercropped with sugarcane system

Sunflower Intercropped Under Young Fruit Trees System

In Egypt, some farmers intercropped sunflower under young fruit trees. This practice is encouraged by the "Higher Council for Edible Oils" in Egypt. The council disseminates this practice between farmers, where selected farmers get intensives to implement the system.

Thus, we suggested using 10% of the area cultivated with young fruit trees to be assigned to this system. Sunflower planting density under this system is 70% of its recommended density.

Relay Intercropping Sunflower with Wheat System

Similar to soybean, sunflower could be relay intercropped with wheat. In China, this intercropping system is used for a better use of land, water, radiation energy, and nutrients (Miao et al. 2016). We suggested implementing this system to increase the cultivated area of sunflower through using 10% of the cultivated area by wheat. Sunflower planting density under this system is 100% of its recommended density.

Table 7.4 indicates that the total cultivated area of sunflower under the suggested intensive systems could be increased from 6585 to 199,837 ha on the national level. This expected increase will occur in the first agro-climatic zone to the fourth agro-climatic zone because sunflower was not cultivated in the fifth agro-climatic zone.

Table 7.4 Potential added area to the actual cultivated area of sunflower as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2015

	Actual cultivated area (ha)	Added area under intercropping sunflower with (ha)				Total area (ha)
		Tomato	Sugarcane	Fruit trees	Relay on wheat	
Zone 1	118	2285	0	1068	10,815	14,286
Zone 2	3909	2608	0	38,002	32,382	76,901
Zone 3	1483	2746	0	27,364	35,717	67,310
Zone 4	1075	1425	1038	6908	30,896	41,342
Zone 5	0	0	0	0	0	0
Total	6585	9064	1038	73,342	109,810	199,839

Cultivation of Sunflower as an Early Summer Crop System

Similar to soybean, sunflower could be cultivated as early summer crop after early sugar beet and faba bean. We suggested using 20% of early sugar beet cultivated area to be assigned to sunflower cultivation. Sunflower planting density under this system is 100% of its recommended density. Early sunflower could also be cultivated after faba bean.

Thus, we suggested using 30% of faba bean cultivated area to be assigned to sunflower cultivation. Sunflower planting density under this system is 100% of its recommended density.

The results in Table 7.5 indicated that using early cultivation for sunflower could increase its cultivated area by extra 47,708 ha.

Table 7.5 Potential added area to the actual cultivated area of sunflower as a result of early cultivation in the agro-climatic zones of Egypt in 2015

	Actual area (ha)	Added area of sunflower after (ha)		Total area (ha)
		Sugar beet	Faba bean	
Zone 1	118	13,023	1709	14,850
Zone 2	3909	11,107	2400	17,416
Zone 3	1483	6844	1161	9488
Zone 4	1075	4329	551	5955
Zone 5	0	0	0	0
Total	6585	35,303	5820	47,708

Maize Intercropping Systems

Maize Intercropped with Summer Tomato System

Maize intercropping with summer tomato is a very successful intercropping system in Egypt (Fig. 7.8). In this system, tomato is transplanted in April, 35–40 days before maize cultivation on one side of raised beds and maize is cultivated on the other side of the raised beds. The benefit of using this system is maize plants perform as sheds over tomato plants and protect its fruits from damage by sun rays (Adigbo et al. 2013). Maize planting density under this system is 60% of its recommended density, whereas tomato planting density is 100% of its recommended density.

We suggested that 40% of the total cultivated area of tomato in each agro-climatic zone will be assigned to this intercropping system.

Maize Intercropped with Peanut System

Sherif et al. (2005) intercropped maize with peanut, where peanut was cultivated in April and maize was cultivated 21 days after peanut cultivation, which resulted in increasing land productivity. Maize planting density under this system is 25% of

Fig. 7.8 Maize intercropped with tomato system

Fig. 7.9 Maize intercropping with peanut

its recommended density (Fig. 7.9). Dahmardeh (2013) indicated that intercropping maize with peanut was advantageous, compared to both sole crops of maize and peanut, where productivity of the unit land was increased.

We suggested that 30% of the total cultivated area of peanut in each agro-climatic zone will be assigned to this intercropping system.

Maize Intercropped with Sorghum

Maize intercropped with sorghum is common system in Upper Egypt. In this system, both crops are cultivated in May and harvest in September. Maize planting density under this system is 33% of its recommended density. Abou-Keriasha et al. (2012) stated that this system has an advantage in increasing aeration between maize plants, as a result of short sorghum plants, compared to maize plants. They also stated that pollination process in maize was enhanced under th, which resulted in an increase in maize productivity.

We suggested that 30% of the total cultivated area of sorghum in each agro-climatic zone will be assigned to this intercropping system.

Table 7.6 presents the potential added area to the total cultivated area of maize as a result of intercropping systems. The results in the table indicated that maize cultivated area could be increased from 938,329 to 966,465 ha, with 3% increase.

Table 7.6 Potential added area to the actual cultivated area of maize as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2015

	Actual cultivated area (ha)	Added area under intercropping maize with (ha)			Total area (ha)
		Tomato	Peanut	Sorghum	
Zone 1	36,358	2285	0	0	38,643
Zone 2	213,734	2608	2218	0	218,560
Zone 3	313,517	2746	1218	4926	322,407
Zone 4	340,637	1425	465	7961	350,488
Zone 5	34,084	147	568	1718	36,517
Total	938,329	9210	4469	14,605	966,615

Flax Intercropping Systems

Flax Intercropped with Sugar Beet System

Intercropping flax with sugar beet could be implemented to increase the cultivated area with flax. Zeneldein (2015) stated that, in this system, sugar beet is cultivated in October and flax in intercropped three weeks after. The planting density of flax was 50% of its recommended density, whereas sugar beet planting density is 100% of its recommended density.

We suggested that 20% of the total cultivated area of sugar beet in each agro-climatic zone will be assigned to this intercropping system.

Flax Intercropped with Faba Bean System

Similarly, flax intercropped with faba bean could have the same benefits of as intercropping flax with sugar beet system in increasing the cultivated area of flax. Abbas and Atalla (2006) stated that under this system the planting density of flax was 50% of its recommended density, which produced the highest land productivity.

We suggested that 10% of the total cultivated area of faba bean in each agro-climatic zone will be assigned to this intercropping system.

Table 7.7 indicates that flax cultivated area could be increased by from 3102 to 19,467 ha, with 528% increase.

The Potential Increases in the Total Cultivated Area of the Selected Oil Crops

Table 7.8 indicates that the total cultivated area of the selected edible oil crops could be increased as a result of the suggested intensive cropping practices. The total cultivated area by the suggested oil crops could be increased by 90%, compared to the actual total cultivated area in 2015.

Table 7.7 Potential added area to the actual cultivated area of flax as a result of intercropping systems in the agro-climatic zones of Egypt in 2015

	Actual area (ha)	Added area (ha) of flax intercropped with		Total area (ha)
		Sugar beet	Faba bean	
Zone 1	426	6511	285	7222
Zone 2	2245	5553	400	8199
Zone 3	431	3422	193	4046
Zone 4	0	0	0	0
Zone 5	0	0	0	0
Total	3102	15,487	878	19,467

Table 7.8 Actual, potential, and total cultivated area of edible oil and percentage of increase in the agro-climatic zones of Egypt in 2015

	Actual area (ha)	Potential area (ha)	Total area (ha)	% of increase
Zone 1	68,713	111,998	180,711	163
Zone 2	264,564	331,763	596,327	125
Zone 3	337,661	307,737	645,398	91
Zone 4	357,473	227,193	584,666	64
Zone 5	34,084	2433	36,517	7
Total	1,062,495	981,123	2,043,618	–

The Projected Cultivated Area of the Selected Oil Crops in 2030

Because Egypt is suffering from water deficiency, it is expected that under climate change in the future, water requirements for the cultivated crops will increase and consequently its cultivated area will be reduced (Ouda et al. 2016). For that reason, reduction in the cultivated area of the selected crops in each agro-climatic zone in Egypt was calculated.

To assess the effect of climate change on water requirements of the studied crops, climate change scenario RCP6.0 resulted from MIROC5 model in 2030 was used in this analysis. It is available from the following website: http://www.ccafs.cgiar.org/marksimgcm#.Ujh1gj-GfMY. The MIROC5 model is one on the CMIP5 General Circulation Models developed by Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology. The model has a horizontal resolution equal to 1.40° × 1.40°. RCP6.0 climate change scenario is one of the four RCPs scenarios produced by MIROC5 model to represent a larger set of mitigation scenarios and have different targets in terms of radiative forcing in 2100. The scenario is a stabilization scenario, in which total radiative forcing is stabilized shortly after

2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions (Fujino et al. 2006; Hijioka et al. 2008).

Because the total assigned amounts of irrigation water to agriculture is fixed and it is unexpected to be increase in the future, in another word the same applied amounts of irrigation water in 2015 will be applied in 2030, thus the cultivated area in 2030 under these circumstances will decrease. Percentage of increase in water requirements for the selected crops and percentage of reduction in the cultivated area in the five agro-climatic zones in Egypt is shown in Tables 7.9 and 7.10.

1. Cotton intercropping systems in 2030

Table 7.11 indicates that the total cultivated area of cotton in 2030 will be decreased from 100,349 ha (Table 7.1) to be 89,843 ha (Table 7.11), with 10% decrease on the national level in 2030. Furthermore, the total cultivated area with cotton after implementing intercropping systems will be reduced from 417,427 (Table 7.1) to 384,446 ha (Table 7.11), with 8% reduction on national level.

2. Soybean intensive cropping systems in 2030

Table 7.12 indicates that the actual cultivated area of soybean could be reduced from 14,130 (Table 7.2) to 11,905 ha (Table 7.12) on national level in 2030, with 16% decrease. Furthermore, intercropping systems could increase the total cultivated area by soybean to 298,655 in 2030 (Table 7.12), which account for 12% deceased than what was obtained in 2015.

The results in Table 7.13 indicated that using early cultivation for soybean could increase its cultivated area by extra 53,715 ha in 2030, which is lower than its counterpart value in 2015 by 28%.

3. Sunflower intensive cropping systems in 2030

Table 7.14 indicates that the total cultivated area of sunflower could be reduced from 6585 ha in 2015 (Table 7.4) to 5932 ha in 2030, with 10% decrease. The potential total cultivated area as a result of intercropping system will be reduced from 199,837 ha in 2015 (Table 7.4) to 182,354 ha, with 9% decrease on the national level.

The results in Table 7.15 indicated that using early cultivation for sunflower could increase its cultivated area by extra 36,410 ha in 2030.

4. Maize intercropping systems in 2030

The results in Table 7.16 indicated that, under climate change in 2030, maize cultivated area will be reduced from 938,329 ha in 2015 (Table 7.6) to 844,716 ha in 2030 (Table 7.16), with 10% decrease. The projected total cultivated area will also be reduced by 10% from 966,465 ha in 2015 (Table 7.6) to 870,807 ha in 2030 (Table 7.16).

Table 7.9 Percentage of increase in water requirements (WR %) of the selected crops and percentage of reduction in the cultivated area (CA %) in 2030

	Wheat		Faba bean		Onion		Sugar beet		Maize	
	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)
Zone 1	4	4	8	7	3	3	9	9	2	2
Zone 2	6	5	9	8	8	7	12	11	7	7
Zone 3	6	6	5	4	10	9	18	15	15	13
Zone 4	10	9	12	10	11	10	29	22	10	9
Zone 5	11	10	13	11	13	12	NC	NC	21	17
Average	7	7	9	8	9	8	17	14	11	10

NC Not cultivated

Table 7.10 Percentage of increase in water requirements (WR %) of the selected summer crops and percentage of reduction in the cultivated area (CA %) in 2030

	Tomato		Peanut		Sorghum		Sugarcane		Fruit trees	
	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)	WR (%)	CA (%)
Zone 1	3	3	NC	NC	NC	NC	NC	NC	3	3
Zone 2	10	9	12	12	NC	NC	NC	NC	10	9
Zone 3	18	15	13	8	15	13	NC	NC	18	15
Zone 4	19	16	15	17	17	14	17	18	19	16
Zone 5	19	16	NC	12	21	17	18	19	19	16
Average	14	12	13	12	18	15	18	19	14	12

NC Not cultivated

Table 7.11 Projected added area to the cultivated area of cotton as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) under relay intercropping		Total area (ha)
		On wheat	On onion	
Zone 1	29,812	20,818	14,111	64,740
Zone 2	39,083	61,222	34,969	135,274
Zone 3	18,462	67,476	22,805	108,743
Zone 4	2486	56,306	16,897	75,689
Zone 5	0	0	0	0
Total	89,843	205,822	88,781	384,446

Table 7.12 Projected added area to the cultivated area of soybean as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) under intercropping soybean with					Total area (ha)
		Maize	Sorghum	Sugarcane	Fruit trees	Relay/wheat	
Zone 1	412	3573	0	0	1550	10,409	15,944
Zone 2	777	19,903	0	0	51,675	30,611	102,966
Zone 3	110	27,330	0	0	34,925	33,737	96,102
Zone 4	10,607	30,840	4505	830	8707	28,153	83,642
Zone 5	0	0	0	0	0	0	0
Total	11,905	81,646	4505	830	96,857	102,910	298,655

Table 7.13 Projected added area to the cultivated area of soybean as a result of early cultivation in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) of soybean after		Total area (ha)
		Sugar beet	Faba bean	
Zone 1	412	17,874	2119	19,993
Zone 2	777	14,897	2943	17,840
Zone 3	110	8693	1479	10,172
Zone 4	10,607	5053	658	5710
Zone 5	0	0	0	0
Total	11,905	46,516	7199	53,715

Table 7.14 Projected added area to the cultivated area of sunflower as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) under intercropping sunflower with				Total area (ha)
		Tomato	Sugarcane	Fruit trees	Relay on wheat	
Zone 1	113	2211	0	1034	10,409	13,767
Zone 2	3619	2364	0	34,450	30,611	71,045
Zone 3	1304	2337	0	23,283	33,737	60,661
Zone 4	896	1197	830	5805	28,153	36,881
Zone 5	0	0	0	0	0	0
Total	5932	8110	830	64,572	102,910	182,354

Table 7.15 Projected added area to the cultivated area of sunflower as a result of early cultivation in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) of sunflower after		Total area (ha)
		Sugar beet	Faba bean	
Zone 1	113	11,916	1589	13,505
Zone 2	3619	9932	2207	12,139
Zone 3	1304	5795	1109	6904
Zone 4	896	3368	494	3862
Zone 5	0	0	0	0
Total	5932	31,011	5399	36,410

Table 7.16 Projected added area to the cultivated area of maize as a result of implementing intercropping systems in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) under intercropping maize with			Total area (ha)
		Tomato	Peanut	Sorghum	
Zone 1	35,726	2284	0	0	38,010
Zone 2	199,037	2607	1950	0	203,594
Zone 3	273,296	2745	1119	4294	281,454
Zone 4	308,400	1424	388	7208	317,419
Zone 5	28,256	146	503	1424	30,329
Total	844,716	9207	3959	12,926	870,807

Table 7.17 Projected added area to the cultivated area of flax as a result of intercropping systems in the agro-climatic zones of Egypt in 2030

	Projected cultivated area (ha)	Projected added area (ha) of flax intercropped with		Total area (ha)
		Sugar beet	Faba bean	
Zone 1	404.7	5957	265	6627
Zone 2	2088	4965	368	7421
Zone 3	396.52	2898	184	3479
Zone 4	0	0	0	0
Zone 5	0	0	0	0
Total	2889	13,820	817	17,527

Table 7.18 Projected, the potential added, and the total cultivated area of edible oil and percentage of increase in the agro-climatic zones of Egypt

	Projected cultivated area (ha)	Projected added area (ha)	Projected Total area (ha)	% of increase
Zone 1	66,468	106,120	172,588	160
Zone 2	245,604	305,674	551,278	124
Zone 3	293,569	264,946	558,515	90
Zone 4	322,389	200,815	523,204	62
Zone 5	29,256	1873	31,129	6
Total	955,286	888,628	1,836,714	89

5. **Flax intercropping systems**

Table 7.17 indicates that flax cultivated area in 2030 will be reduced from 3102 ha in 2015 (Table 7.7) to 2889 ha in 2030 (Table 7.17). The total cultivated area after implementing intercropping system will be reduced from 19,467 ha 2015 (Table 7.7) to 17,527 ha 2030 (Table 7.17), with 10% decrease.

6. **The projected total cultivated area of the selected oil crops in 2030**

Table 7.18 indicates that the cultivated area of the selected edible oil crops could be increased as a result of the suggested intensive cropping practices in 2030. However, the increase will be lower than its counterpart in 2015. The total cultivated area could be increased by 89%, compared to the total actual cultivated area in 2030.

Crop Rotations in Egypt

In Southwest Egypt, a promising region is located, namely Sharq El-Owainat. It is located at Sahara Desert lies approximately 290 km from the nearest city and 210 km from the Toshka lakes. The Nubian Sandstone Aquifer System, buried beneath the sand, allows agriculture to survive in the middle of the desert. The aquifer is the only source of water for Egyptians living away from the Nile River. The soil of this region is sandy soil, with low fertility.

Two-year and three-year crop rotations were implemented in Sharq El-Owainat to produce oil crops. These rotations started in the summer season of 2004 and ended in the winter season of 2006/07. Sprinkler irrigation was the used systems to deliver water to the cultivated crops. The only source of fertilizer was the organic manure. The aim of implementing crop rotations in this region was to increase the production of oil crops. Additionally, to encourage investment in this region for production of these crops.

With respect to the two-year crop rotation (Fig. 7.10), it contained 75% oil crops (sunflower, canola, and soybean). The results indicated that the yield of sunflower was increased from 2.67 ton/ha in the first year of the rotation to 3.00 ton/ha, with 9% increase. The yield of canola was increased by 11% from 4.56 to 5.04 ton/ha. In addition, in the second section of the rotation, soybean yield was increased by 8% from 2.88 ton/ha in the first year of the rotation to 3.12 ton/ha in the second year of the rotation. Lastly, faba bean yield was increased by 8% from 4.61 ton/ha in the first year of the rotation to 4.99 ton/ha in the second year of the rotation.

The three-year crop rotation (Fig. 7.11) contained 66% oil crops, namely peanut, canola, sunflower, and soybean. It also contained 50% legume crops, namely peanut, soybean, and faba bean. In the third year of the rotation and in the first section, the yield of peanut was 5.04 ton/ha, compared to 4.50 ton/ha in the first year of the rotation, thus 12% increase. Furthermore, canola yield was increased to 3.60 ton/ha in the third year of the rotation, compared to 3.24 ton/ha in the first year of the rotation, thus increased by 11% increase. With respect to sunflower in the second section of the rotation, its yield was 3.17 ton/ha in the third year, compared to 3.00 ton/ha in the first year, with 6% increase. The yield of faba bean was also increased by 5% from 4.61 ton/ha in the first year to 4.84 ton/ha in the third year of the rotation.

In the third section of the rotation, soybean yield was increased by 4% from 3.00 ton/ha in the first year to 3.12 ton/ha in the third year of the rotation. Similarly, wheat yield was increased by 6% from 7.67 ton/ha in the first year to 8.10 ton/ha in the third year of the rotation.

Fig. 7.10 Implemented two-year oil crop rotation in Sharq El-Owainat, Egypt

Year 1	Year 2
Sunflower Canola	Soybean Faba bean
Soybean Faba bean	Sunflower Canola

Year 1	Year 2	Year 3
Peanut Canola	Sunflower Faba bean	Soybean Wheat
Sunflower Faba bean	Soybean Wheat	Peanut Canola
Soybean Wheat	Peanut Canola	Sunflower Faba bean

Fig. 7.11 Implemented three-year oil crop rotation in Sharq El-Owainat, Egypt

Year 1	Year 2	Year 3
Peanut Canola	Sunflower Faba bean	Soybean Flax
Sunflower Faba bean	Soybean Flax	Peanut Canola
Soybean Flax	Peanut Canola	Sunflower Faba bean

Fig. 7.12 Suggested three-year oil crops rotation in the marginal lands of Egypt

Suggested Crop Rotation in the New Lands of Egypt

One way of increasing the production of edible oil crops in Egypt is to expand its cultivation in the marginal lands of sandy soil surrounding the Nile Delta and Valley. A suggested crop rotation (Fig. 7.12) could be implemented in this area to contain 85% oil crops, namely peanut, canola, soybean, and flax. It is also characterized by having 50% legume crops, namely peanut, faba bean, and soybean.

Conclusion

Agriculture is the producer of food using the available natural resources, namely soil, water, and weather resources. Increasing the efficiency of using these resources could increase food production and availability, as well as reduce food insecurity. When lands are limited, intensive cropping such as intercropping and successive cropping could fully utilize available water and labor.

Our results showed that the gap between production–consumption of edible oil in Egypt could be minimized through intensive cropping of five oil crops, namely cotton, soybean, sunflower, maize, and flax. Our results indicated that cotton intercropping systems could increase its cultivated area by 317,078 ha. Soybean cultivated area could be increased by 385,017 ha if intensive cropping was implemented. Similarly, intensive cropping could increase sunflower cultivated area by 234,376 ha. Maize and flax cultivated area could be increased by 28,284 and 16,365 ha, respectively, under implementing intercropping systems.

Under climate change in 2003, the cultivated area of these five selected oil crops will be reduced, as well as the added area as a result of intensive cropping systems. The cultivated area of the selected oil crops will increase by 294,603; 340463; 212,832; 26,092 and 17,637 ha for cotton, soybean, sunflower, maize, and flax, respectively, which is lower than the potential added area in 2015.

Thus, to solve the problem of food gaps in Egypt, decisions makers should introduce and implement the methods of intensive cropping to farmers on the national level.

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Chapter 8
Suggested Crop Rotations to Increase Food Security and Reduce Water Scarcity

Introduction

Crop rotation is the production of different economically important plant species in recurrent succession on a particular field or group of fields (Bruns 2012). It is a critical feature of all organic cropping systems because it provides the principal mechanism for building healthy soils, a major way to control pests, and a variety of other benefits (Mohler 2001). Crop rotation means changing the type of crop grown on a particular piece of land from year to year. Crop rotation is one of the most effective agricultural control strategies. It involves arrangement of crops planted on same field; the succeeding crops should belong to different families (Huang et al. 2003). The planned rotation may vary from two, three year or longer period (Kamel et al. 2016). Some of the general benefits of using rotations are: improve or maintain soil fertility, improve soil structure (Raimbault and Vyn 1991), increase soil organic matter levels (Bremer et al. 2008), and enhance mycorrhizal associations (Johnson et al. 1992). Crop rotation reduces the spread of pests, which provide better weed control and interrupt insects and disease cycles (Karlen et al. 1994).

Crop rotation increased water use efficiency and improved crop nutrient use efficiency (Tanaka et al. 2005). It reduces risk of weather damage and thus reduces yield losses and that will increase net profit of farmers (Kaye et al. 2007). It could also improve grain quality and reduce grain yield variability (Varvel 2000). Furthermore, crop rotation could save on the applied irrigation water to crops (Ouda et al. 2016).

The appropriate choice of crops within the rotation and their sequence is crucial, where each crop species has slightly different characteristics, e.g., N demanding or N2 fixing (Mohler 2001), shallow or deep rooting, amount, and quality of crop residue returned. These characteristics along with existing biotic and abiotic factors determine the ultimate suitability of a break crop in a given cropping system (Malik 2010).

S. Ouda et al., *Crop Rotation*, https://doi.org/10.1007/978-3-030-05351-2_8

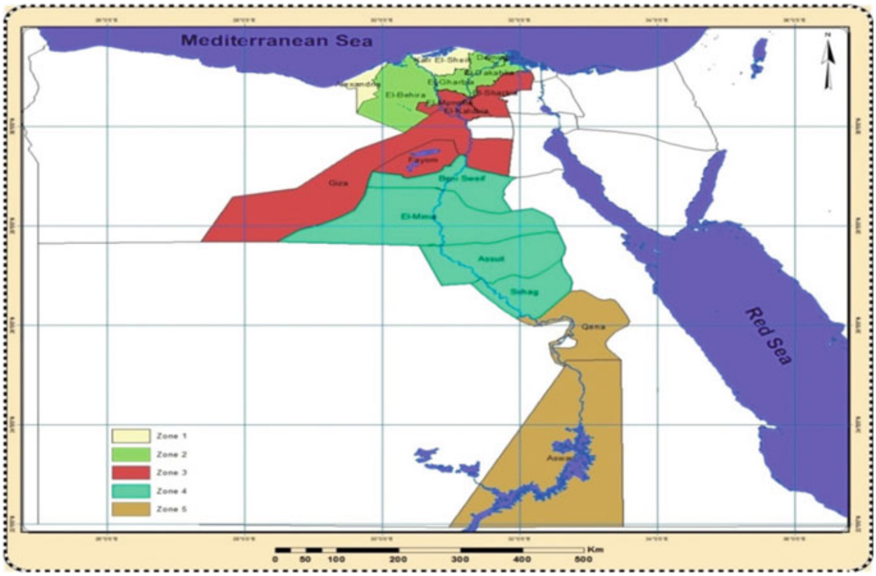

Fig. 8.1 Map of the agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

Thus, using crop rotations could help in the sustainable use of natural agricultural resources as well as increase the agricultural productivity of unit land and unit of irrigation water under the prevailing conditions of water scarcity. As a result, the probability of attaining food security for strategic crops will increase and that will help in improving living standards and poverty elevation of rural population.

The objective of this chapter was to present the prevailing crop rotations in the different soil types of the five agro-climatic zones of Egypt. Furthermore, different crop rotations were suggested to be implemented in these agro-climatic zones to increase food production and save on the applied irrigation.

Figure 8.1 shows the five agro-climatic zones developed by Ouda and Noreldin (2017).

Water Requirements of the Crop Rotations

Both the values of monthly evapotranspiration (ETo) in each agro-climatic zone and the values of crop-specific coefficients (Kc) of the cultivated crops in the crop rotations are used in the calculation of water requirements. The BISm model (Snyder et al. 2004) was used to calculate values of ETo and Kc in 2016. The BISm calculates ETo using Penman–Monteith equation. The model provides an easy method to determine Kc values for a large number of crops, as affected by the weather in a certain region, irrigation method, as well as season length.

Table 8.1 presents the annual values of solar radiation (SRAD), maximum (TMAX), minimum (TMIN), and dew point (TDEW) temperatures, wind speed (WSEP), and ETo values in the five agro-climatic zones of Egypt in 2016.

Table 8.2 shows the planting and harvest dates as well as the season length of the selected crops.

The dates of Kc growth stages and values in the first, second, and third agro-climatic zones are presented in Table 8.3. The date of initial Kc (Kc_{ini}), the date of mid-season Kc (Kc_{ini}), and the date of end season Kc (Kc_{ini}) for the studied crop were similar in the first, second, and third agro-climatic zones as well as its values (Table 8.3).

Similarly, the date of Kc growth stages and its values was comparable in the fourth and fifth agro-climatic zones and it was different than its counterpart values in the first, second, and third agro-climatic zones (Table 8.4).

Water requirements for the crops existing in the prevailing and suggested crop rotations were calculated. It is worth mentioning that water requirements for crops existing in the prevailing crop rotations were calculated under surface irrigation with 60% application efficiency, which is the prevailing system in the old lands, surrounding the Nile River. In the new lands existing around the old lands, modern irrigation systems are prevailing, namely sprinkler and drip systems. The use of either systems depends on crop type. Application efficiency of sprinkler and drip systems is 75 and 85%, respectively.

With respect to water requirements of the crops existing in the suggested crop rotation, we assumed that cultivation on raised beds will be implemented, where 20% of the applied irrigation water to surface irrigation could be saved (Abouelenein et al. 2010). Additionally, we assumed that improvement of the application efficiency of either sprinkler or drip system by 10% could be done through using irrigation scheduling (Taha 2012).

According to earlier research on water requirements of cowpea intercropped with maize system, Zohry et al. (2017) indicated that the applied water to maize was used

Table 8.1 Annual averages of weather elements and ETo values in the agro-climatic zones in 2016

Zone	SRAD ($MJ/m^2/day$)	TMAX (°C)	TMIN (°C)	WSED (m/s)	TDEW (°C)	ETo (mm/day)
Zone 1	19.3	26.4	18.4	2.7	14.0	5.1
Zone 2	19.4	27.7	18.2	2.6	13.4	5.4
Zone 3	20.4	30.3	15.3	2.2	9.4	6.1
Zone 4	22.1	28.6	14.1	2.1	4.8	6.9
Zone 5	22.5	33.1	16.8	2.0	2.9	7.8
Mean	20.8	29.2	16.6	2.3	8.9	6.3
Range[a]	3.2	6.7	1.6	0.7	5.1	2.7

[a] Range = Highest value minus lowest value

Table 8.2 Planting and harvest dates and season length for the selected crops

Crop	Planting date	Harvest date	Season length
Clover	15-Oct	1-Apr	169
Cotton	15-Apr	15-Aug	154
Faba bean	25-Oct	25-Apr	152
Flax	15-Nov	13-Apr	150
Maize	15-May	1-Sep	110
Onion	15-Nov	15-Apr	152
Rice	15-May	16-Sep	125
Sorghum	15-May	1-Sep	110
Soybean	15-May	25-Aug	103
Sugar beet	15-Oct	12-Apr	180
Sugarcane	15-Feb	14-Feb	365
Sunflower	15-May	15-Aug	93
Tomato (winter)	1-Oct	1-Mar	152
Tomato (summer)	1-May	1-Sep	124
Wheat	15-Nov	18-Apr	155

Table 8.3 Date of Kc growth stages and its values for the studied field crops in the first, second, and third agro-climatic zones

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Faba bean	29-Nov	24-Dec	25-Apr	0.29	0.99	0.21
Clover	26-Oct	3-Dec	1-Apr	0.26	1.13	0.40
Cotton	7-Apr	23-Jul	15-Aug	0.30	0.93	0.46
Flax	10-Dec	21-Jan	13-Apr	0.31	1.10	0.25
Lentil	10-Nov	24-Dec	25-Apr	0.23	0.99	0.21
Maize	6-Jun	3-Jul	1-Sep	0.24	1.04	0.58
Onion	30-Nov	24-Dec	15-Apr	0.30	1.19	0.54
Rice	14-Jun	30-Jun	16-Sep	0.37	1.02	0.78
Sorghum	1-Jun	30-Jun	1-Sep	0.20	1.06	0.50
Soybean	4-Jun	30-Jun	25-Aug	0.24	1.11	0.39
Sugar beet	11-Nov	4-Jan	12-Apr	0.27	1.15	0.95
Sunflower	2-Jun	25-Jun	15-Aug	0.24	1.09	0.37
Tomato (winter)	8-Nov	16-Dec	1-Mar	0.26	1.10	0.64
Tomato (summer)	1-Jun	2-Jul	1-Sep	0.25	1.10	0.65
Wheat	16-Dec	22-Jan	18-Apr	0.31	1.06	0.19

Table 8.4 Date of Kc growth stages and its values for the studied crops in the fourth and fifth agro-climatic zones

Crop	Data of growth stages			Kc value		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Faba bean	30-Nov	25-Dec	25-Apr	0.26	0.99	0.18
Clover	27-Oct	4-Dec	1-Apr	0.26	1.15	0.40
Cotton	8-Apr	24-Jul	15-Aug	0.24	0.93	0.45
Flax	11-Dec	22-Jan	13-Apr	0.29	1.10	0.25
Lentil	11-Nov	25-Dec	25-Apr	0.21	0.99	0.18
Maize	7-Jun	4-Jul	1-Sep	0.19	1.03	0.58
Onion	30-Nov	25-Dec	15-Apr	0.28	1.19	0.54
Sorghum	2-Jun	1-Jul	1-Sep	0.16	1.06	0.50
Soybean	5-Jun	1 Jul	25-Aug	0.19	1.11	0.39
Sugar beet	12-Nov	5-Jan	12-Apr	0.23	1.15	0.95
Sugarcane	18-Apr	21-Oct	14-Feb	0.4	1.25	0.75
Sunflower	3-Jun	26-Jun	15-Aug	0.20	1.09	0.37
Tomato (winter)	9-Nov	17-Dec	1-Mar	0.22	1.10	0.64
Tomato (summer)	1-Jun	3-Jul	1-Sep	0.20	1.10	0.65
Wheat	17-Dec	23-Jan	18-Apr	0.29	1.08	0.17

by both cowpea and maize, when both crops were intercropped. Thus, we assumed that, for any intercropping system, the applied water to the main crop in the system is enough to fulfill the needs of the secondary crop in the system.

Crop Rotations in Egypt

We presented in this section the prevailing crop rotation in each agro-climatic zone. This prevailing crop rotation was modified and another crop rotation was suggested. The modification was done with the aim of increasing land and water productivity.

The First Agro-climatic Zone

Crop Rotation in Calcareous Soil

The prevailing crop rotation in the calcareous soil of the first agro-climatic zone is presented in Fig. 8.2. In this rotation, wheat precedes sunflower in the same piece of

Year 1	Year 2	Year 3
Wheat Sunflower	Barley Maize	Clover (full season) Tomato
Barley Maize	Clover (full season) Tomato	Wheat Sunflower
Clover (full season) Tomato	Wheat Sunflower	Barley Maize

Fig. 8.2 Prevailing crop rotation in the calcareous soil of the first agro-climatic zone

land in the first section, as well as barley precedes maize in the second section. Both crop sequences are expected to cause soil deterioration. Furthermore, the rotation contains only one legume crop, namely clover.

The suggested crop rotation (Fig. 8.3) included a legume crop in each section to improve soil properties. Soybean replaced sunflower in the first section, and faba bean replaced barley in the second section. Moreover, two intercropping systems were included, namely cowpea intercropped with maize in the second section and sunflower intercropped with in the third section. Cowpea intercropped with maize resulted in reduction in maize-associated weeds (Zohry 2005) and an increase in maize yield by 10% (Hamd-Alla et al. 2014). Detailed description in cowpea intercropped with maize system exists in Chap. 3.

In the third section, sunflower intercropped with tomato was preceded by clover. In this intercropping system, shading by sunflower plants is presented to tomato plants, which improved fruit set and consequently yield quality (Abdel 2006). Detailed description in sunflower intercropped with tomato system exists in Chap. 7.

Table 8.5 shows that the total applied water to the prevailing rotation was higher than the suggested rotation by 3351 m^3/ha, which is equal to 20% of the applied water to the prevailing rotation.

Crop Rotation in Salt-Affected Soil

The prevailing crop rotation in the salt-affected soil contained salinity-tolerant crops. However, sugar beet and wheat preceding rice have harmful effect on the soil. Further-

Year 1	Year 2	Year 3
Wheat Soybean	Faba bean Cowpea/maize	Clover (full season) Sunflower/tomato
Faba bean Cowpea/maize	Clover (full season) Sunflower/tomato	Wheat Soybean
Clover (full season) Sunflower/tomato	Wheat Soybean	Faba bean Cowpea/maize

Fig. 8.3 Suggested crop rotation in calcareous soils of the first agro-climatic zone

Table 8.5 Water requirements for the prevailing and suggested crop rotations in the calcareous soil of the first agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	6417	Wheat	5134
Sunflower	8367	Soybean	6694
Barley	5450	Faba bean	4251
Maize	9350	Cowpea/maize	7480
Clover (full season)	9433	Clover (full season)	7546
Tomato	10,700	Sunflower/tomato	8560
Total	49,717		39,665
Saved amount per hectare		3351	
Percentage of saving		20	

more, this rotation is expected to consume large amount of irrigation water because rice is cultivated twice and both sugar beet and clover have high water requirements. In addition, it contained only one legume crop (Fig. 8.4).

To overcome the consequences of cultivating two cereal crops (winter and summer) in the same piece of land, fahl clover could be cultivated after rice and before wheat, as an early winter crop in the first section of the rotation (Fig. 8.5). Fahl clover is a variety of Egyptian clover, which has stem branching ability, rapid growth, and large forage yield. It is only cut once and it could be cultivated as early winter crop in September and stays until the beginning of November, where its growing season is between 60 and 70 days (Bakheit et al. 2016). Sheha et al. (2014) reported that cultivation of fahl clover before sugar beet and after rice increases sugar beet yield as a result of nitrogen fixation, which accelerates the microbial activity of the soil. In this three-crop sequence, wheat is cultivated in November and harvested in April. Rice is cultivated in May and harvested in August, and then, fahl clover is cultivated September and harvested in early November.

Year 1	Year 2	Year 3
Sugar beet Rice	Clover Maize	Wheat Rice
Wheat Rice	Sugar beet Rice	Clover Maize
Clover Maize	Wheat Rice	Sugar beet Rice

Fig. 8.4 Prevailing crop rotation in salt-affected soil of the first agro-climatic zone

Year 1	Year 2	Year 3
Wheat Rice Fahl clover	Faba bean/sugar beet Tomato	Clover (full season) Sunflower
Faba bean/sugar beet Tomato	Clover (full season) Sunflower	Wheat Rice Fahl clover
Clover (full season) Maize	Wheat Rice Fahl clover	Faba bean/sugar beet Tomato

Fig. 8.5 Suggested crop rotation in salt-affected soil of the first agro-climatic zone of Egypt

Fig. 8.6 Faba bean intercropped with sugar beet

In the second section of the rotation, faba bean intercropped with sugar beet was included (Fig. 8.6). In this system, sugar beet is cultivated with 100% of its recommended planting density and faba bean is cultivated using 25% of its recommended planting density. As a result, the farmer could obtain 100 and 25% of sugar beet and faba bean yield, respectively (Abd El-Zaher and Gendy 2014).

Water requirements for the crops existing in the prevailing and suggested crop rotations are presented in Table 8.6. It is worth noting that leaching requirements for the cultivated crops were considered to be 10% of the applied irrigation water for each crop. The table revealed that the amount of saved irrigation water as a result of implementing the suggested rotations will be 3418 m^3/ha, which represents 16% of the total applied water to the prevailing rotation.

Table 8.6 Water requirements for the prevailing and suggested crop rotations in salt-affected soil of the first agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Sugar beet	10,010	Wheat	5646
Rice	12,760	Rice	10,208
Wheat	7058	Fahl clover	3188
Rice	12,760	Faba been/sugar beet	8008
Clover	10,377	Tomato	9416
Maize	10,285	Clover (full season)	8302
		Maize	8228
Total	63,250		52,996
Saved amount per hectare (m^3/ha)		3418	
Percentage of saving (%)		16	

The Second Agro-climatic Zone

Crop Rotation in Sandy Soil

In sandy soil of Egypt, farmers tend to cultivate large areas of peanut in this type of soil. However, continuous cultivation of peanut results in continuous decline in peanut yield due to deterioration of soil microbial community (Wang and Chen 2005). It reduces the diversity of bacteria in both species and quantity, lowers the number of fungi species, and increases mold quantity (Xie et al. 2007).

The prevailing crop rotation in the sandy soil (Fig. 8.7) included peanut in two of its three sections. Furthermore, wheat preceded peanut and sugar beet preceded maize. In addition, the rotation contained only one legume crop, namely clover.

The suggested crop rotation (Fig. 8.8) contains legume crops in each section. In the first section of the rotation, the system of maize intercropping with peanut (Sherif et al. 2005) is implemented. Dahmardeh (2013) indicated that intercropping maize

Year 1	Year 2	Year 3
Clover (full season) Peanut	Sugar beet Maize	Wheat Peanut
Wheat Peanut	Clover (full season) Peanut	Sugar beet Maize
Sugar beet Maize	Wheat Peanut	Clover (full season) Peanut

Fig. 8.7 Prevailing crop rotation in the sandy soil in the second agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Wheat Maize/peanut	Pea Sunflower Maize (late)	Clover (full season) Maize
Pea Sunflower Maize (late)	Clover (full season) Maize	Wheat Maize/peanut
Clover (full season) Maize	Wheat Maize/peanut	Pea Sunflower Maize (late)

Fig. 8.8 Proposed crop rotation in the sandy soil of the second agro-climatic zones of Egypt

with peanut was advantageous, compared to both sole crops of maize and peanut, where productivity of the unit land was increased. Detailed description of the system is presented in Chap. 7.

In the second section of the rotation, three-crop sequence was implemented, where pea preceded sunflower and followed by late-season maize (cultivated in July). In this system, pea is cultivated in September and harvested in February in the following year. In March, sunflower is cultivated and harvested in June. In July, maize is cultivated as late crop in July and harvested in October before the cultivation of winter crops in November. In the third section of the rotation, full season clover preceded maize.

Sprinkler or drip systems are the prevailing irrigation systems in this type of soil. Table 8.7 indicates that the suggested rotation could save 273 m^3/ha, which accounts for 2% of the total applied water to the prevailing rotation.

Table 8.7 Water requirements for the prevailing and suggested crop rotations in sandy soil of the second agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	7880	Wheat	4812
Peanut	8933	Maize/peanut	8040
Wheat	5347	Pea	3588
Peanut	8933	Sunflower (early)	6306
Sugar beet	8535	Maize (late)	9867
Maize	8970	Clover (full season)	7092
		Maize	8073
Total	48,598		47,778
Saved amount per hectare (m^3/ha)		273	
Percentage of saving (%)		2	

Crop Rotation in Clay Soil

The prevailing crop rotation in the clay soil of the second agro-climatic zone (Fig. 8.9) included two legume crops, namely faba bean and clover. However, continuous cultivation of maize after wheat could have bad effect on soil properties.

In the first section of the rotation (Fig. 8.10), three-crop sequence was implemented, where wheat followed by maize followed by fahl clover. In this system, wheat is cultivated in November and harvested in April, maize is cultivated in May and harvested in September, and fahl clover is cultivated in September and harvested in the first week of November before the following winter crop (Zohry et al. 2017).

In the second section of the rotation, relay intercropping cotton on wheat system (Zohry 2005) was implemented. Furthermore, Zhang et al. (2008) stated that in relay intercropping cotton on wheat system fertilizer use efficiency increased, which could reduce environmental risks of leaching it to groundwater. Detailed description of the system is presented in Chap. 3.

In the third section of the rotation, faba bean is followed by maize intercropping with tomato system (Mohamed et al. 2013). Abdelmageed et al. (2003) indicated that this system is implemented by the farmers and is very popular. Furthermore, maize could modify the micro-climate for tomato and protect the tomato fruits from sun damage. Incidence of powdery mildew that occurs in tomato plants was reduced when maize is intercropped with it (Hao 2013). Ijoyah and Fanen (2012) stated that different patterns of roots (deep for tomato and shallow for maize) exploit soil moisture and nutrients in different soil layers, which minimize plants competition.

Changing monoculture cultivation in the prevailing rotation to intercropping systems in the suggested rotation resulted in irrigation water saving. The saved amount was 1525 m^3/ha or 9% of the applied irrigation water to the prevailing crop rotation (Table 8.8).

Year 1	Year 2	Year 3
Faba bean Tomato	Clover (2 cuts) Cotton	Wheat Maize
Wheat Maize	Faba bean Tomato	Clover (2 cuts) Cotton
Clover (2 cuts) Cotton	Wheat Maize	Faba bean Tomato

Fig. 8.9 Prevailing crop rotation in the clay soil of the second agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Wheat Maize Fahl clover	Cotton relay intercropped on wheat	Faba bean Maize/tomato
Cotton relay intercropped on wheat	Faba bean Maize/tomato	Wheat Maize Fahl clover
Faba bean Maize/tomato	Wheat Maize Fahl clover	Cotton relay intercropped on wheat

Fig. 8.10 Proposed crop rotation in the clay soil of the second agro-climatic zone of Egypt

Table 8.8 Water requirements for the prevailing and suggested crop rotations in clay soil of the second agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Faba bean	6117	Wheat	5346
Tomato	11,400	Maize	7974
Wheat	6683	Fahl clover	3507
Maize	9967	Cotton/wheat	16453
Clover (2 cuts)	3467	Faba bean	4894
Cotton	14,233	Maize/tomato	9120
Total	51,867		47,294
Saved amount per hectare (m^3/ha)		1525	
Percentage of saving (%)		9	

The Third Agro-climatic Zone

Crop Rotation in Salt-Affected Soil

The prevailing crop rotation in salt-affected soil of the third agro-climatic zone contained clover cultivated twice as short season and full season. It also contained cotton, wheat, and rice cultivated once (Fig. 8.11).

Regarding the suggested crop rotation (Fig. 8.12), it contained cotton relay intercropped on wheat system (Zohry 2005), three-crop sequence system (sugar beet, rice, and then fahl clover; Sheha et al. 2014) and two-crop sequence (full season clover followed by maize).

Water requirements for prevailing and suggested crop rotations in salt-affected are presented in Table 8.9. The results in that table indicated that 1539 m^3/ha or 7% saving in the applied irrigation water to the prevailing rotation.

Year 1	Year 2	Year 3
Clover (2 cuts) Cotton	Clover (full season) Maize	Wheat Rice
Wheat Rice	Clover (2 cuts) Cotton	Clover (full season) Maize
Clover (full season) Maize	Wheat Rice	Clover (2 cuts) Cotton

Fig. 8.11 Prevailing crop rotation in the salt-affected soil in the third agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Cotton relay intercropped on wheat	Sugar beet Rice Fahl clover	Clover (full season) Maize
Sugar beet Rice Fahl clover	Clover (full season) Maize	Cotton relay intercropped on wheat
Clover (full season) Maize	Cotton relay intercropped on wheat	Sugar beet Rice Fahl clover

Fig. 8.12 Suggested crop rotation in the salt-affected soil of the third agro-climatic zone of Egypt

Table 8.9 Water requirements for the prevailing and suggested crop rotations in salt-affected soil of the third agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (2 cuts)	4613	Cotton/wheat	15,315
Cotton	11,532	Sugar beet	8226
Wheat	8012	Rice	12,246
Rice	15,308	Fahl clover	3858
Clover (full season)	11,532	Clover (full season)	9226
Maize	12,448	Maize	9958
Total	63,445		58,829
Saved amount per hectare (m^3/ha)		1539	
Percentage of saving (%)		7	

Crop Rotation in Clay Soil

The prevailing crop rotation in the third agro-climatic zone contained the traditional crop sequences, namely wheat followed by maize, full season clover followed by sunflower, and short season clover followed by cotton (Fig. 8.13).

Year 1	Year 2	Year 3
Wheat Maize	Clover (2 cuts) Cotton	Clover (full season) Sunflower
Clover (full season) Sunflower	Wheat Maize	Clover (2 cuts) Cotton
Clover (2 cuts) Cotton	Clover (full season) Sunflower	Wheat Maize

Fig. 8.13 Prevailing crop rotation in the clay soil of the third agro-climatic zone of Egypt

In the suggested crop rotation (Fig. 8.14) and in the first section, cowpea intercropped with maize system (Hamd-Alla et al. 2014) is cultivated after wheat.

In the second section of the crop rotation, another three-crop sequence was cultivated. In this sequence, clover is cultivated in September and harvest in April, soybean is cultivated as an early summer crop in May and harvested in the end of July, and sunflower is cultivated in August and harvested in October before cultivation of the winter crop in November.

In the third section, cotton could be relay intercropped with onion (Zohry 2005) to increase land profitability. In this system, onion plays a vital role in reducing some cotton insects, such as cotton leafworm (Badawy and Shalaby 2015). Detailed description of the system is presented in Chap. 3 (Fig. 8.15).

Table 8.10 shows that the applied irrigation water to the suggested rotation will be lower than the applied amounts to the prevailing rotation. Implementing the suggested crop rotation could save 907 m^3/ha, which amounts to 5% of the applied water to the prevailing rotation.

Year 1	Year 2	Year 3
Wheat Cowpea/maize	Clover (full season) Soybean (early) Sunflower	Cotton relay intercropped on onion
Clover (full season) Soybean (early) Sunflower (late)	Cotton relay intercropped on onion	Wheat Cowpea/maize
Cotton relay intercropped on onion	Wheat Cowpea/maize	Clover (full season) Soybean (early) Sunflower

Fig. 8.14 Suggested crop rotation in the clay soil of the third agro-climatic zone of Egypt

Fig. 8.15 Cotton relay intercropped with onion

Table 8.10 Water requirements for the prevailing and suggested crop rotations in clay soil of the third agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	7283	Wheat	5826
Maize	11,317	Cowpea/maize	9054
Clover (full season)	10,483	Clover (full season)	8386
Sunflower	10,233	Soybean (early)	5691
Clover (2 cuts)	4193	Sunflower (late)	6834
Cotton	10,483	Cotton/onion	15,480
Total	53,992		51,271
Saved amount per hectare (m^3/ha)		907	
Percentage of saving (%)		5	

The Fourth Agro-climatic Zone

Crop Rotation in Sandy Soil

The prevailing crop rotation in the sandy soil of the fourth agro-climatic zone (Fig. 8.16) is similar to the one existed in the second agro-climatic zone with one difference, namely maize is replaced by sorghum. Sorghum is very popular crop in the fourth and fifth agro-climatic zones. It could withstand the high temperature

Year 1	Year 2	Year 3
Clover (full season) Peanut	Sugar beet Sorghum	Wheat Peanut
Wheat Peanut	Clover (full season) Peanut	Sugar beet Sorghum
Sugar beet Sorghum	Wheat Peanut	Clover (full season) Peanut

Fig. 8.16 Prevailing crop rotation in the sandy soil in the fourth agro-climatic zone of Egypt

prevailing in these zones. However, cultivation of peanut twice and sugar beet once causes spread of soil nematodes.

In the first section of the suggested crop rotation (Fig. 8.17), sesame replaced peanut as a non-host nematode. In the second section of the rotation, three-crop sequence was implemented where fahl clover cultivation followed peanut cultivation and preceded wheat cultivation.

In the third section of the crop rotation, faba bean was followed by cowpea intercropped with sorghum system. Abou-Keriasha et al. (2011) indicated that sorghum yield was increased under intercropping it with cowpea by 8%, compared to sole sorghum planting. Furthermore, associated weeds with sorghum were decreased by 81%, compared to sole planting of sorghum. The existence of cowpea is very important as a feed summer crop in this rotation. Description of the system is presented in Chap. 6).

Implementing the suggested crop rotation in the sandy soil of the fourth agro-climatic zone could result in saving the applied irrigation water for the prevailing crop rotation by 6%, which amounts for 972 m^3/ha, compared to the applied amount for the prevailing rotation (Table 8.11).

Year 1	Year 2	Year 3
Clover (full season) Sesame	Wheat Peanut	Faba bean Cowpea/sorghum
	Fahl clover	
Wheat Peanut Fahl clover	Faba bean Cowpea/sorghum	Clover (full season) Sesame
Faba bean Cowpea/sorghum	Clover (full season) Sesame	Wheat Peanut Fahl clover

Fig. 8.17 Suggested crop rotation in the sandy soil in the fourth agro-climatic zone of Egypt

Table 8.11 Water requirements for the prevailing and suggested crop rotations in sandy soil of the fourth agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	8613	Clover (full season)	7752
Peanut	9013	Sesame	8555
Wheat	6493	Wheat	5844
Peanut	9013	Peanut	8112
Sugar beet	9107	Fahl clover	4172
Sorghum	10,167	Faba bean	6500
		Cowpea/sorghum	9150
Total	52,406		50,085
Saved amount per hectare (m^3/ha)		774	
Percentage of saving (%)		4	

Crop Rotation in Clay Soil

The crops cultivated in the prevailing crop rotation contained two legume crops, namely full season clover and faba bean. Furthermore, sorghum is preceded by wheat, where both are cereal crops (Fig. 8.18).

In the first section of the suggested crop rotation, full season clover was followed by sunflower intercropped with tomato system (Chap. 7, Abdel 2006). In the second section of the rotation, three-crop sequence was cultivated, where fahl clover was cultivated between sorghum and wheat. In the third section of the rotation, faba bean was followed by soybean intercropped with maize system (Chap. 3; Sherif and Gendy 2012) (Fig. 8.19).

Irrigation water saving by 3068 m^3/ha could be attained when the suggested rotation is implemented. This amount represents 14% of the applied water to the prevailing crop rotation (Table 8.12).

Year 1	Year 2	Year 3
Clover (full season) Tomato	Faba bean Maize	Wheat Sorghum
Wheat Sorghum	Clover (full season) Tomato	Faba bean Maize
Faba bean Maize	Wheat Sorghum	Clover (full season) Tomato

Fig. 8.18 Prevailing crop rotation in the clay soil in the fourth agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Clover (full season) Sunflower/tomato	Wheat Sorghum Fahl clover	Faba bean Soybean/maize
Wheat Sorghum Fahl clover	Faba bean Soybean/maize	Clover (full season) Sunflower/tomato
Faba bean Soybean/maize	Clover (full season) Sunflower/tomato	Wheat Sorghum Fahl clover

Fig. 8.19 Suggested crop rotation in the clay soil in the fourth agro-climatic zone of Egypt

Table 8.12 Water requirements for the prevailing and suggested crop rotations in clay soil of the fourth agro-climatic zone

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	9433	Clover (full season)	7546
Tomato	14,433	Sunflower/tomato	11,546
Wheat	8117	Wheat	6494
Sorghum	13,167	Sorghum	10,534
Faba bean	7217	Fahl clover	4319
Maize	12,750	Faba bean	5774
		Soybean/maize	10,200
Total	65,117		55,913
Saved amount per hectare (m^3/ha)		2901	
Percentage of saving (%)		13	

The Fifth Agro-climatic Zone

Crop Rotations for Sugarcane

Crop rotation in the fifth agro-climatic zone is called sugarcane rotation because sugarcane is the main crop in it. In this rotation, sugarcane occupies one half of its area. The rotation contains six sections and implemented in eight years, where there are two preliminary years. These two preliminary years allow the farmers to produce new cane every year to produce good quality sugarcane.

In the first preliminary year, new cane introduced in the rotation, whereas in the second preliminary year, the first ratoon is produced from the cane cultivated in the first preliminary year, and new cane is introduced in the underneath section. In the first year of the rotation, second ratoon is produced from the first ratoon cultivated in the second preliminary year, and new cane is introduced in the underneath section. This procedure continues to the end of the rotation. Thus, in the first year of the rotation and after the two preliminary years, new cane, first and second ratoon exist in each year.

Sugarcane plants are grown under surface irrigation with 60% application efficiency, which consumes large amount of irrigation water not only because it has long growing season, but also it has large above-ground biomass. Cultivation on raised beds is not suitable for sugarcane plants because of its large above-ground biomass.

In Egypt, sugarcane could be cultivated twice as a fall or spring crop. The fall sugarcane is cultivated in September and October and harvested after 16 months. Fallow exists before the new cane in each year of the rotation (Fig. 8.20).

The spring sugarcane is cultivated in February and March and harvested after 12 months. In this rotation, clover is cultivated and harvested before new cane cultivation, where two cuts of clover can be harvested (Fig. 8.21).

To increase land and water productivity in both fall and spring sugarcane rotation, intercropping systems could be implemented with sugarcane. Sugarcane offers a unique potential for intercropping because it is planted in wide rows (100 cm) and takes several months to develop its canopy, during which time the soil and solar energy go to waste (Nazir et al. 2002). The growth rate of sugarcane during its early growth stages is slow, with leaf canopy providing sufficient uncovered area for growing another crop (Watto and Mugera 2015). In this case, the intercropped crop will not need any extra irrigation water as it will use the applied water to sugarcane to fulfill its required water. Furthermore, intercropping on sugarcane provide extra income for farmers during the early growth stage of sugarcane.

In the suggested fall crop rotation (Fig. 8.22), faba bean, onion, or wheat could be intercropped on the new cane. In faba bean intercropping with sugarcane system (Fig. 8.23a), faba bean is cultivated in October in two rows with 50% of its recommended planting density (Farghly 1997). Intercropping with faba bean has the greatest potential to fix nitrogen (Shoko and Tagwira 2005). Since nitrogen fertilizer is a substantial cost component of sugarcane cropping system, the use of faba bean as a secondary crop in the system plays a considerable role in reduction of production costs (El-Geddawy et al. 1988).

Regarding onion intercropped with sugarcane, the system is very successful in south Egypt. Hossain et al. (2004) stated that onion exerted the least detrimental effect

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Fallow New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) New cane	1stRatoon
Faba bean Sorghum	Fallow New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (one cut) New cane
Wheat Sorghum	Lentil Sorghum	Fallow New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow New cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow New cane	1stRatoon	2ndRatoon

Fig. 8.20 Prevailing fall sugarcane crop rotation in the fifth agro-climatic zone of Egypt

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) New cane	1stRatoon
Faba bean Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (one cut) New cane
Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) New cane	1stRatoon	2ndRatoon

Fig. 8.21 Prevailing spring sugarcane crop rotation in the fifth agro-climatic zone of Egypt

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Fallow Faba bean/new cane	1stRatoon
Faba bean Sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Onion/new cane
Wheat Sorghum	Lentil Sorghum	Fallow Wheat/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Wheat/new cane	1stRatoon	2ndRatoon

Fig. 8.22 Suggested fall sugarcane crop rotation in the fifth agro-climatic zone of Egypt

on the emergence and tillering of sugarcane and final yield of sugarcane. Higher yield of cane due to intercropping with onion was reported as it reduces the incidence of some insects in sugarcane (Parashar et al. 1979). In this system, onion is planted in October in two rows with 80% of its recommended planting density (Zohry 1997).

Another successful intercropping system for wheat is intercropping with sugarcane (Fig. 8.23b). In this case, wheat will not need any extra irrigation water as it will use the applied water to sugarcane to fulfill its required needs for water. Furthermore, intercropping wheat on sugarcane provides extra income for farmers during the early growth stage of sugarcane. Under intercropping wheat with sugarcane system (Fig. 8.4), sugarcane is cultivated in September and wheat is cultivated in November with 40% of its recommended planting density and then wheat is harvested in April. This system produces 40% of wheat yield with no reduction in sugarcane yield (Ahmed et al. 2013).

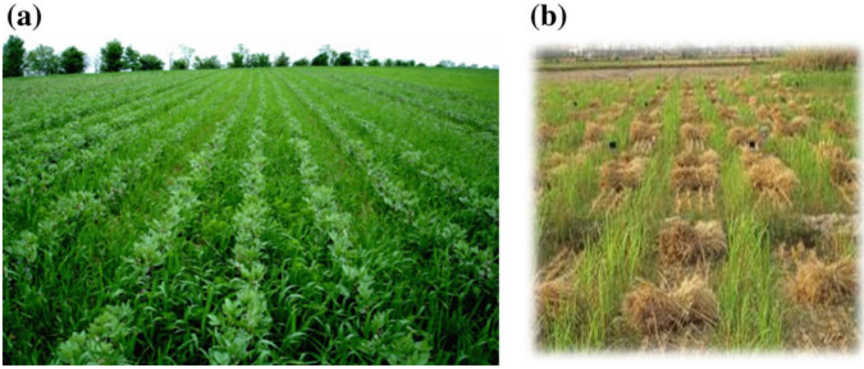

Fig. 8.23 Faba bean intercropped with sugarcane (**a**) and wheat intercropped with sugarcane (**b**)

In the suggested spring sugarcane rotation (Fig. 8.24), intercropping with new sugarcane could be implemented, where soybean, sesame, or sunflower is intercropped. Intercropping soybean with sugarcane (Fig. 8.25a) is a common practice by the farmers in this area (Abou-Keriasha, et al. 1997). According to Sundara (2000), soybean is one of the important intercrop suitable and compatible with sugarcane. This is mainly due to the fact that soybean has adapted well to the climatic conditions in this area. Details of this system are presented in Chap. 7.

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) Soybean/new cane	1stRatoon
Faba bean Sorghum	Clover (2 cuts) Sesame/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sesame/new cane
Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sunflower /new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sunflower /new cane	1stRatoon	2ndRatoon

Fig. 8.24 Suggested spring sugarcane crop rotation in the fifth agro-climatic zone of Egypt

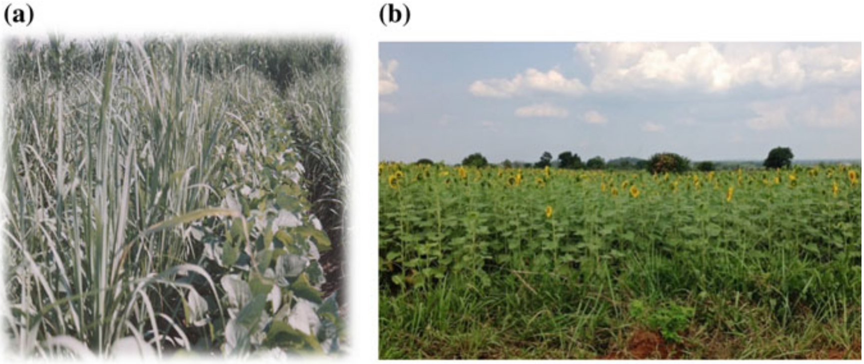

Fig. 8.25 Soybean intercropped with sugarcane (**a**) and sunflower intercropped with sugarcane (**b**)

In intercropping sesame with spring sugarcane system, the competition over solar radiation between sesame plants and sugarcane plants was low and does not negatively affect sugarcane yield because of the morphological characteristics of sesame leaves being erect and does not cause any shading over the growing sugarcane plants. Sesame's recommended planting density is 50% in its intercropping system with sugarcane (Abou-Keriasha et al. 1997).

El-Gergawi et al. (2000) intercropped sunflower with sugarcane (Fig. 8.25b). However, Abou-Keriasha et al. (1997) indicated that competition over solar radiation between sunflower plants and sugarcane plants was high because sunflower plants are longer than sugarcane plants in that growth stage.

The results in Table 8.13 indicated that both the prevailing and the suggested fall sugarcane rotation consumed 1,887,523 m^3 of irrigation water in the eight years of its duration. However, this amount of water is used to irrigate 70 crops in the prevailing rotation and 78 crops in the suggested rotation. For that reason, the suggested rotation has higher water productivity, in addition to having higher land productivity due to the implemented intercropping systems.

Likewise, in the prevailing spring sugarcane rotation (Table 8.14), the 78 crops cultivated in it consumed 1,746,635 m^3 of irrigation water. Whereas, the suggested spring sugarcane rotation consumed the same amount of irrigation water by 86 crops cultivated in it. Thus, the suggested rotation has higher water productivity and land productivity.

Table 8.13 Water requirements for the prevailing and suggested fall sugarcane rotations in the fifth agro-climatic zone of Egypt

	Prevailing fall rotation		Suggested fall rotation	
	Total amount (m^3)	No. of cultivated crops	Total amount (m^3)	No. of cultivated crops
First preliminary	193,828	11	193,828	12
Second preliminary	223,394	10	223,394	11
First year	252,111	9	252,111	10
Second year	243,578	8	243,578	9
Third year	243,578	8	243,578	9
Fourth year	243,728	8	243,728	11
Fifth year	243,578	8	243,578	10
Sixth year	243,728	8	243,728	11
Total	1,887,523	70	1,887,523	78

Table 8.14 Water requirements for the prevailing and suggested spring sugarcane rotations in the fifth agro-climatic zone of Egypt

	Prevailing spring rotation		Suggested spring rotation	
	Total amount (m^3)	No. of cultivated crops	Total amount (m^3)	No. of cultivated crops
First preliminary	176,217	12	180,368	13
Second preliminary	205,783	11	209,934	12
First year	234,500	10	238,651	11
Second year	225,967	9	230,118	10
Third year	225,967	9	230,118	10
Fourth year	226,117	9	230,268	10
Fifth year	225,967	9	230,118	10
Sixth year	226,117	9	230,268	10
Total	1,746,635	78	1,779,839	86

Conclusion

In overpopulated countries like Egypt, there is a gap between production and consumption of cereal crops, oil crops, sugar crops, legume crops, and forage crops. Thus, unconventional procedures are needed to increase crops productivity, manage irrigation water more efficiently, and increase crops production in short time. This magic solution could be attained by implementing crop rotation that includes intercropping systems. Thus, sustainable use of land and water resources could be attained by implementing crop rotations.

Different soil types in each agro-climatic zone required different crops in each rotation. Improving soil properties could be obtained by inclusion of legume crops in the rotation and/or implementing intercropping systems with legume crop as companion crop. Water saving occurs as a result of implementing intercropping systems on raised beds with the suggested crop rotation. Our analysis showed that increasing the number of crops included in the rotation through intercropping system could consume less amount of water, compared to the amount consumed by the prevailing rotations in all the agro-climatic zones of Egypt.

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Chapter 9
Crop Rotation Could Alleviate Climate Change Damage

Introduction

Climate change is expected to have many adverse impacts on various sectors, yet agriculture is considered to be the most tangible affected sector (El-Massah and Omran 2014). Because of the relationships between climate, crop, water, and soil are complex with many biological processes involved (Rao et al. 2011), any alteration in the prevailing temperature or precipitation patterns will disturb these process including crop yields, and crops water requirements, as well as soil fertility (IPCC 2007). Any increase in temperatures could lead to a net deficit in atmospheric water content, and thus, excessive evaporation from soil, water, and plant surfaces would occur (Kimball et al. 2002). Climate change has already caused significant impacts on water resources and food security, where land ecosystems would require more water to match increased water demand and, consequently, to prevent drought (IPCC 2013). It was reported that climate change is expected to negatively affect crops productivity (Ouda et al. 2013) and cause increases in water requirements for crops in Egypt (Ouda et al. 2015).

Crop rotation could be the solution to climate change problems, namely loss in crop productivity, rise in required water for crop irrigation, and loss in soil fertility. It could increase land productivity by implementing intercropping systems in one or two growing seasons and cultivation of three crops per year on raised beds. It could also increase land productivity through. Crop rotation could also increase water productivity, where intercropping systems use less water that monocultures (Kamel et al. 2016). Furthermore, cultivation on raised beds not only increases the yield of the cultivated crop, but also reduces the applied irrigation water to it (Abouelenein et al. 2010). Additionally, implementing crop rotations could prevent soil degradation through the inclusion of legumes within the crop rotation and implementing intercropping systems with legumes. Thus, crop rotation could be used as an adaptation strategy to climate change.

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Projection of the required irrigation water to fulfill the needs of the cultivated crops in a country in the future necessitates the knowledge of the expected values of the weather elements in that expected to prevail in the future, or what is known as a climate change scenario. The recent report by the Intergovernmental Panel on Climate Change, namely The Fifth Assessment Report (IPCC 2013), presented a large number of comprehensive climate models and Earth System Models stated that “the results of the report form the core of the climate system projections.” These climate models produce climate change scenarios known as “Representative Concentration Pathways.” These scenarios were based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) and it is used to replace the SRES scenarios in the “IPCC Fourth Assessment Report (AR4)” released in 2007. These climate change scenarios are known by RCPs, namely RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (Wayne 2013).

Because weather parameters are the only factors affecting evapotranspiration (ETo), it is the most important hydrological and meteorological variable to reflect the change in the climate of the future (Rahman et al. 2015). ETo is the key factor in determining crop water requirements in various development stages of the growing crops, where it is a combination of soil evaporation and crop transpiration (Gardner et al. 1985). It was reported that ETo values will be a rise in Egypt in 2030, as a result of climate change. It was also revealed that temperature rise by 1 °C may increase ETo value by about 4–5%, whereas a rise by 3 °C may increase ETo value by about 15% (Eid 2001). Attaher et al. (2006) and Khalil (2013) concluded that the future climate change in 2100 will increase potential irrigation demands, due to the increase in ETo. Ouda et al. (2016) stated that the value of ETo will increase by an average of 9% in 2030 and by an average of 13% in 2040 in Egypt.

In this chapter, we used the knowledge we learned from the previous chapters to suggest intensive crop rotations to be implemented in 2030 under climate change. The suggested crop rotations were designed to tolerate the stressful effects of climate change, namely loss in the productivity of its crops, rise in the required irrigation water of its crops, and degradation of its cultivated soils. Thus, the suggested crop rotations could maximize food production and diminish irrigation water losses, which will lead to maximize land and water productivities. Additionally, these suggested crop rotations were compared to the prevailing crop rotations, with respect to the applied irrigation amounts for the cultivated crops in each rotation.

The assessment was done in the five agro-climatic zones of Egypt developed by Ouda and Noreldin (2017) (Fig. 9.1).

Projection of Water Requirements of the Crop Rotations

To assess the effect of climate change on ETo, climate change scenario RCP6.0 resulted from MIROC5 model in 2030 was used in this analysis. It is available from the following Web site: http://www.ccafs.cgiar.org/marksimgcm#.Ujh1gj-GfMY. The MIROC5 model is one of the CMIP5 General Circulation Models developed

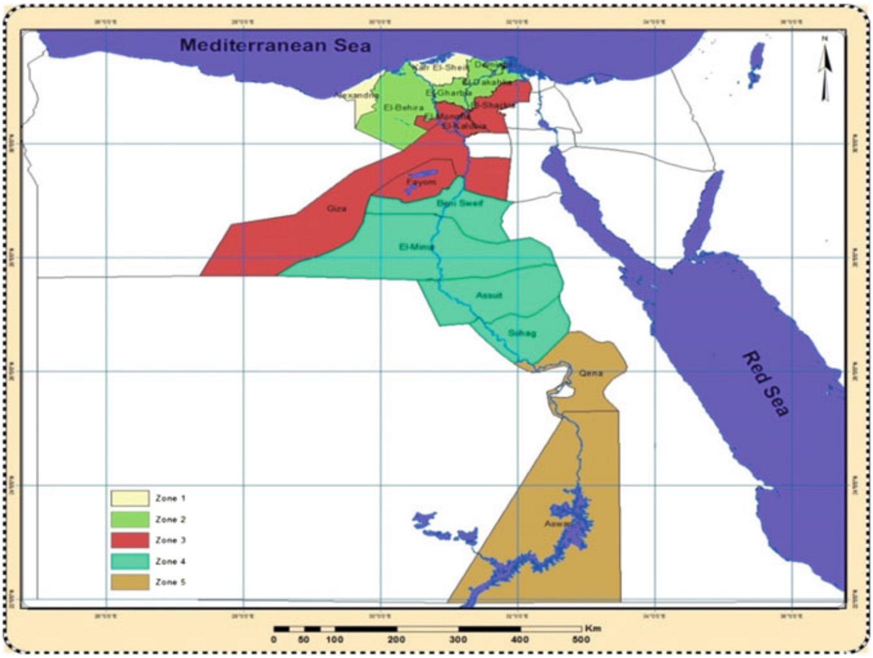


Fig. 9.1 Map of agro-climatic zones of Egypt. *Source* Ouda and Noreldin (2017)

by Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology. The model has a horizontal resolution of 1.40° × 1.40°.

RCP6.0 climate change scenario is one of the four RCPs scenarios produced by MIROC5 model to represent a larger set of mitigation scenarios and have different targets in terms of radiative forcing in 2100. The scenario is a stabilization scenario, in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions (Fujino et al. 2006; Hijioka et al. 2008).

The BISm model (Snyder et al. 2004) was used to calculate the values of ETo and Kc of the cultivated crops in 2030 and consequently to calculate water requirements of the selected crops. The BISm calculates ETo using Penman–Monteith equation (Allen et al. 1998). Penman–Monteith equation is widely recommended because of its detailed theoretical base and its accommodation of small time periods (Shahidian et al. 2012).

Planting and Harvest Dates of the Studied Field Crops

Under climate change in 2030 and as a result of the rise in air temperature, it is expected that planting date will be earlier by 5–7 days. Morsy (2015) simulated the effect of early planting for wheat and maize under climate change in 2030 and found that early planting of both crops resulted in reduction of its yield losses. Furthermore, it is also expected that season length of the cultivated crops will be reduced under climate change. Khalil et al. (2009) reported that wheat season length was reduced by 5 days in 2030, as a result of acceleration in its growing season. Similar results were obtained by Ouda et al. (2009) for maize under climate change in 2030. Thus, in our analysis, we assumed that in 2030 planting date will be 5 days earlier and season length will be reduced. Table 9.1 presents the expected planting and harvest dates for the selected crops in 2030.

Projection of the Crop-Specific Coefficients

Crop-specific coefficient (Kc) is an important determinant in irrigation scheduling for crops. The variation and magnitude of Kc are important for accurate determination of water consumptive use of the crops and consequently irrigation scheduling for crops. Kc takes into account the relationship between atmosphere, crop physiology, and agricultural practices (Reddy et al. 2015). Furthermore, the Kc value is affected by all the factors that influence soil water status, for instance, the irrigation

Table 9.1 Expected planting and harvest dates for the selected crops in 2030

Crop	Planting date	Harvest date	Season length (days)
Clover	10-Oct	23-Mar	165
Cotton	10-Mar	5-Aug	149
Faba bean	20-Oct	18-Apr	150
Maize	10-Mar	20-Aug	103
Rice	10-May	7-Sep	121
Sorghum	10-May	20-Aug	103
Soybean	10-May	16-Aug	99
Sugar beet	10-Oct	5-Apr	178
Sugarcane	15-Feb	14-Feb	365
Sunflower	10-May	7-Aug	90
Wheat	10-Nov	9-Apr	151
Tomato (winter)	28-Apr	23-Aug	118
Tomato (summer)	28-Sep	23-Feb	149

method and frequency (Wright 1982), the weather factors, the soil characteristics and the agronomic techniques that affect crop growth (Annandale and Stockle 1994). Additionally, different environmental conditions between regions allow variation in variety selection and crop developmental stages, which affect Kc (Allen et al. 1998). Moreover, elevated air temperatures and water vapor pressure deficit over the growing seasons could cause temporal and transient leaf stomata closure (Baker et al. 2007), impeding plants to transpire at its full potential (Ko et al. 2009). Thus, under climate change conditions, it is expected that the Kc values will be increased, which will consequently affect the water amount required to be applied to the cultivated crops.

The BISm model (Snyder et al. 2004) was used to calculate the values of Kc for each growing stage using ETo values and planting and harvest dates in 2030. The results indicated that the projected date of each Kc growth stage of the selected field crops was similar in the first, the second, and the third agro-climatic zone (Table 9.2).

Furthermore, the projected dates of Kc growth stages were similar in the fourth and fifth agro-climatic zones (Table 9.3) and different than its counterpart values in Table 9.2.

The results in Table 9.4 indicated that the projected values of Kc_{ini} and Kc_{end} were different in the first, second, and third agro-climate zones, where it took a decreasing trend. Furthermore, the value of Kc_{med} was similar in these three agro-climatic zones.

Table 9.2 Projected date of Kc growth stages for the studied crops in the first, second, and third agro-climatic zones in 2030

Crop	Data of growth stages		
	Kc_{ini}	Kc_{mid}	Kc_{end}
Clover	21-Oct	28-Nov	23-Mar
Cotton	1-Apr	16-Apr	5-Aug
Faba bean	25-Nov	19-Dec	18-Mar
Maize	30-May	26-Jun	20-Aug
Onion	24-Nov	18-Dec	7-Apr
Rice	8-Jun	23-Jun	7-Sep
Sorghum	26-May	22-Jun	20-Aug
Soybean	29-May	23-Jun	16-Aug
Sugar beet	5-Nov	29-Dec	5-Apr
Sugarcane	13-Apr	16-Oct	9-Feb
Sunflower	28-May	19-Jun	7-Aug
Tomato (winter)	27-Apr	26-Jun	23-Aug
Tomato (summer)	4-Nov	12-Dec	23-Feb
Wheat	10-Dec	16-Jan	9-Apr

Table 9.3 Projected date of Kc growth stages for the studied crops in the fourth and fifth agro-climatic zones in 2030

Crop	Data of growth stages		
	Kc_{ini}	Kc_{mid}	Kc_{end}
Clover	20-Oct	27-Nov	23-Mar
Cotton	31-Mar	15-Apr	5-Aug
Faba bean	24-Nov	18-Dec	18-Mar
Maize	29-May	24-Jun	20-Aug
Onion	23-Nov	19-Dec	7-Apr
Sorghum	25-May	21-Jun	20-Aug
Soybean	28-May	22-Jun	16-Aug
Sugar beet	4-Nov	28-Dec	5-Apr
Sugarcane	12-Apr	14-Oct	9-Feb
Sunflower	26-May	17-Jun	7-Aug
Tomato (winter)	26-Apr	25-Jun	23-Aug
Tomato (summer)	3-Nov	11-Dec	23-Feb
Wheat	9-Dec	15-Jan	9-Apr

With respect to the projected values of Kc, the results in Table 9.5 showed similar trend to the existed in the first, second, and third zones. The projected values of Kc_{ini} and Kc_{end} were different in the fourth and fifth agro-climate zones.

The value of Kc_{ini} is affected by soil evaporation, which is determined from the ETo rate and irrigation frequency (Snyder et al. 2004). Thus, ETo rate is increasing from the first agro-climatic zone to the third agro-climatic zone. Because the interval between irrigation events is long due to the characteristics of the prevailing clay soil in the agro-climatic zones, reduction in the value of Kc_{ini} occurs. Regarding Kc_{mid} and Kc_{end}, both depend on the difference in daily net radiation, soil heat flux density, crop morphology effects on turbulence, and physiological differences between the crop and reference crop (Allen et al. 1998).

Irrigation Water Management Under Climate Change

Under the expected change in climate, it is essential to improve irrigation water management in agriculture and reduce unnecessary losses in the present time, adapt this behavior, and carry it with us for our future generations. Efficient irrigation water management of crops requires accurate irrigation scheduling which, in turn, requires accurate measurement of crop water requirement.

In Chap. 8, we suggested a crop rotation in each soil type of each agro-climatic zone. In these rotations, we assumed that cultivation on raised beds will be implemented, where 20% of the applied irrigation water to surface irrigation could be

Table 9.4 Projected values of Kc of the studied field crops in the first, second, and third agro-climatic zones in 2030

Crop	First agro-climatic zone			Second agro-climatic zone			Third agro-climatic zone		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Clover	0.24	1.15	0.39	0.23	1.15	0.38	0.22	1.15	0.37
Cotton	0.28	0.95	0.49	0.27	0.95	0.49	0.25	0.95	0.49
Faba bean	0.29	1.00	0.21	0.25	1.00	0.20	0.25	1.00	0.19
Maize	0.23	1.06	0.60	0.22	1.06	0.60	0.20	1.06	0.60
Onion	0.28	1.21	0.54	0.27	1.21	0.54	0.26	1.21	0.54
Rice	0.35	1.00	0.77	0.33	1.00	0.77	0.30	1.00	0.77
Sorghum	0.19	1.06	0.50	0.18	1.06	0.50	0.17	1.06	0.50
Soybean	0.23	1.11	0.40	0.22	1.11	0.40	0.20	1.11	0.40
Sugar beet	0.25	1.16	0.96	0.24	1.16	0.96	0.23	1.16	0.96
Sunflower	0.23	1.08	0.38	0.22	1.08	0.36	0.20	1.08	0.36
Tomato (W)	0.24	1.11	0.66	0.22	1.11	0.66	0.20	1.12	0.66
Tomato (S)	0.24	1.09	0.64	0.23	1.09	0.64	0.22	1.09	0.64
Wheat	0.29	1.08	0.19	0.28	1.08	0.18	0.28	1.08	0.17

Table 9.5 Projected values of Kc of the studied field crops in the fourth and fifth agro-climatic zones in 2030

Crop	The fourth agro-climatic zone			The fifth agro-climatic zone		
	Kc_{ini}	Kc_{mid}	Kc_{end}	Kc_{ini}	Kc_{mid}	Kc_{end}
Clover	0.20	1.15	0.36	0.19	1.15	0.35
Cotton	0.23	0.95	0.49	NC	NC	NC
Faba bean	0.23	1.00	0.18	0.22	1.00	0.17
Maize	0.19	1.06	0.60	0.17	1.06	0.60
Onion	0.25	1.21	0.54	0.23	1.22	0.50
Sorghum	0.16	1.06	0.50	0.15	1.06	0.50
Soybean	0.19	1.11	0.40	0.17	1.11	0.40
Sugar beet	0.21	1.16	0.96	NC	NC	NC
Sugarcane	0.40	1.25	0.75	0.40	1.25	0.75
Sunflower	0.19	1.08	0.38	0.17	1.08	0.36
Tomato (winter)	0.19	1.12	0.66	0.18	1.01	0.65
Tomato (summer)	0.20	1.09	0.64	0.19	1.01	0.65
Wheat	0.26	1.08	0.16	0.24	1.08	0.16

NC not cultivated

saved as stated by Abouelenein et al. (2010). We also assumed that improvement in the application efficiency of either sprinkler or drip system by 10% could be done through using irrigation scheduling (Taha 2012).

In this chapter, we assumed that, in 2030, the suggested crop rotations in Chap. 8 will be adapted by the Egyptian farmers. Therefore, it will be implemented and it became poplar and prevailing in the five agro-climatic zones of Egypt. Thus, we suggested other crop rotations to be implemented in each of the agro-climatic zones. Furthermore, we assumed that an extra 5% of the applied irrigation water to crops cultivated in both old and new lands will be saved, as a result of implementing improved management production package. Regarding sugarcane, we assumed that it will be irrigated by gated pipes, which will save 10% of the applied irrigation water to sugarcane.

We also suggested that using intercropping systems to increase land productivity, where two crops could be harvested from a unit of land. Moreover, using intercropping systems with legume crops could improve soil fertility and reduce soil erosion (Dwivedi et al. 2015). Double benefits could be obtained from the inclusion of legume crop in the intercropping system, namely deep roots of legume crops penetrate far into the soil and use moisture and nutrients from deeper soil layers, whereas shallow roots of cereal crops fix the soil at the surface and thereby help to reduce erosion (Machado 2009). Growing legumes with cereals results in N2 fixation in the soil and consequently increases organic content (Hauggaard-Nielsen et al. 2006).

Finally, water requirements for the crops existed in the prevailing and suggested crop rotations was calculated in both old and new lands in 2030 using RCP6.0 climate change scenario resulted from MIROC5 climate change model. We also assumed that.

Percentage of Increase in Crops Water Requirements in 2030

BISm model (Snyder et al. 2004) was used to calculate water requirements for the selected crops in 2030. Comparison between these values and its counterpart values presented in Chap. 8 calculated in 2016 revealed low increases in the first agro-climatic zone, compared to the fifth agro-climatic zone (Table 9.6).

It worth noting that cotton, sugar beet, and peanut are not cultivated in the fifth agro-climatic zone. Furthermore, rice is not cultivated in the fourth and fifth agro-climatic zone, and sugarcane is only cultivated in the fourth and fifth agro-climatic zones (Table 9.6).

Table 9.6 Percentage of increase in the water requirements of the selected crops in 2030

Crop	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Clover	5	6	8	9	10
Cotton	5	12	20	22	NC
Faba bean	8	9	11	12	13
Maize	2	7	19	10	21
Onion	3	8	10	11	13
Rice	4	11	14	15	20
Peanut	NC	12	13	NC	NC
Sorghum	2	7	15	17	21
Soybean	4	14	19	20	21
Sugar beet	9	12	18	29	NC
Sugarcane	NC	NC	NC	17	18
Sunflower	4	8	14	19	20
Tomato (winter)	5	10	18	19	19
Tomato (summer)	10	13	15	16	19
Wheat	4	6	8	10	11

NC not cultivated

Crop Rotations in the Agro-climatic Zones of Egypt in 2030

Crop rotations were suggested to be implemented in 2030 to increase land and water productivity, in addition to maintain soil sustainability. Thus, alleviating the harmful impact of climate change on food production.

The First Agro-climatic Zone

Crop Rotation in Calcareous Soil

The prevailing crop rotation in the calcareous soil of the first agro-climatic zone is presented in Fig. 9.2. It contained a legume crop in each section and two intercropping systems. Details on cowpea intercropped with maize system (Hamd-Alla et al. 2014) is presented in Chap. 3 and details on sunflower intercropped with tomato system (Abdel 2006) is presented in Chap. 6.

The suggested crop rotation (Fig. 9.3) will contain different intercropping systems. In the first section of the rotation and in the winter season, wheat intercropped with tomato system could be implemented. In this system, wheat plants protect tomato plants from low temperature in January and February (Abd El-Zaher et al. 2013). Furthermore, Fernandez-Munoz et al. (1995) indicated that exposing tomato plants to low temperature usually reduce pollen production, shed, viability, and tube growth. Pressman et al. (1997) indicated that higher water use efficiency is obtained as a result of implementing this system, where tomato grows tap deep strong root systems facilitate the absorption of soil moisture deeper than wheat root system. As a result, tomato roots leave the soil in a good mechanical condition.

Thus, in this system, tomato seedling is cultivated at the end of September on raised beds with 100% of its recommended planting density on one side of the raised beds. Wheat seeds are sown after 45 days in four rows on the other side of the raised beds with 67% of its recommended planting density. Under this system, wheat plants share the applied irrigation water and fertilizer with tomato. This system guaranteed that tomato will continue to give fruits until the end of March. On the contrary, when tomato is planted solely, its life cycle was ceased in the end of December. Although

Year 1	Year 2	Year 3
Wheat Soybean	Sugar beet Cowpea/maize	Clover (full season) Sunflower/tomato
Sugar beet Cowpea/maize	Clover (full season) Sunflower/tomato	Wheat Soybean
Clover (full season) Sunflower/tomato	Wheat Soybean	Sugar beet Cowpea/maize

Fig. 9.2 Expected prevailing crop rotation in calcareous soils of the first agro-climatic zone in 2030

Year 1	Year 2	Year 3
Wheat/tomato Cowpea/sunflower	Onion/sugar beet Maize/soybean	Clover (full season) Maize/tomato
Onion/sugar beet Maize/soybean	Clover (full season) Maize/tomato	Wheat/tomato Cowpea/sunflower
Clover (full season) Maize/tomato	Wheat/tomato Cowpea/sunflower	Onion/sugar beet Maize/soybean

Fig. 9.3 Suggested crop rotation in calcareous soils of the first agro-climatic zone in 2030

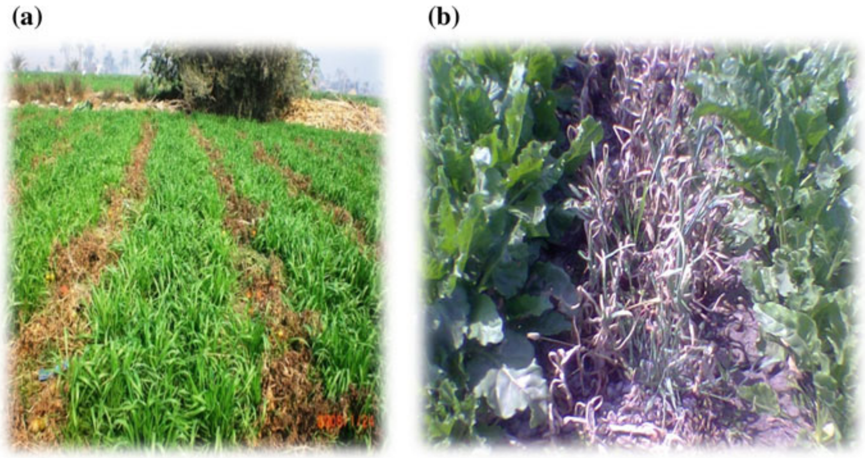


Fig. 9.4 Wheat intercropped with tomato (**a**) and onion intercropped with sugar beet (**b**)

67% of wheat planting density was cultivated, its productivity increased under this system to be 80% of its recommended density (Fig. 9.4a).

In the summer season in the first section of the rotation (Fig. 9.3), intercropping cowpea with sunflower system is implemented (Zohry et al. 2018a, b). Detailed on this system is presented in Chap. 6.

In the winter season in the second section, onion intercropped with sugar beet is suggested (Fig. 9.4b). In this system, onion is intercropped with sugar beet with 33% of its recommended planting density. Sugar beet is cultivated in October with 100% of its recommended planting density and one month later onion is cultivated. The benefit of this system is onion reduces the number of nematodes in the soil and improves sugar beet quality (Farghaly et al. 2003).

In the summer season, maize intercropping with soybean (Sherif and Gendy 2012) is cultivated. Detailed on this system is presented in Chap. 3.

In the third section of the rotation, clover is cultivated in the winter season (Fig. 9.3). Clover is the main leguminous forage crop grown in Egypt cultivated in the winter season. Cultivation of clover suppresses weeds and provides a disease break in cereal-dominated crop rotations (El-Nahrawy 2011). Cultivation of clover

Table 9.7 Water requirements for the expected prevailing and the suggested crop rotations in the calcareous soil of the first agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	5542	Wheat/tomato	5835
Soybean	7301	Cowpea/sunflower	8267
Sugar beet	9946	Onion/sugar beet	9448
Cowpea/maize	7747	Maize/soybean	6936
Clover (full season)	8319	Clover (full season)	7903
Sunflower/tomato	10,358	Maize/tomato	9840
Total	49,213		48,229
Water saving per hectare(m^3/ha) 328			
Water saving (%) 2			

increased residual soil organic matter (Jabbar et al. 2011) and fix atmospheric nitrogen adding significant amounts of nitrogen to the soil (Nair 2015).

Moreover, in the third section, maize intercropped with tomato system is implemented (Mohamed et al. 2013). Detailed on this system is presented in Chap. 7.

It worth noting that this crop rotation is very profitable for the farmer, where it contained 11 crops compared to 8 crops in the prevailing crop rotation. The implemented intercropping systems in the winter and summer seasons could save on the applied irrigation water, it could produce more food, compared to the prevailing crop rotation, and it could fight soil degradation because it contains a legume crop in each section (Fig. 9.3).

Table 9.7 showed that the total applied water to the prevailing rotation was higher than the suggested rotation by 328 m^3/ha, which equal 2% of the applied water to the prevailing rotation.

Crop Rotation in Salt-Affected Soil

The prevailing crop rotation in the salt-affected soil contained salinity-tolerant crops and is presented in Fig. 9.5. It contained a legume crop in each section and one intercropping system, namely faba bean intercropped with sugar beet (Abd El-Zaher and Gendy 2014). Detailed on this system is presented in Chap. 8.

In the suggested crop rotation and in the first section (Fig. 9.6), onion is intercropped with sugar beet (Farghaly et al. 2003) and cowpea is intercropped on sunflower (Zohry et al. 2018a, b, Chapter 7) which were implemented.

To overcome the consequences of cultivating two sequence cereal crops (winter and summer) in the same piece of land, fahl clover could be cultivated after rice and before wheat, as an early winter crop in the second section of the crop rotation

Year 1	Year 2	Year 3
Wheat Rice Fahl clover	Faba bean/sugar beet Tomato	Clover (full season) Sunflower
Faba bean/sugar beet Tomato	Clover (full season) Sunflower	Wheat Rice Fahl clover
Clover (full season) Maize	Wheat Rice Fahl clover	Faba bean/sugar beet Tomato

Fig. 9.5 Expected prevailing crop rotation in salt-affected soil of the first agro-climatic zone in 2030

Year 1	Year 2	Year 3
Onion/sugar beet Cowpea/sunflower	Clover (full season) Cowpea/maize	Wheat Rice Fahl clover
Wheat Rice Fahl clover	Onion/sugar beet Cowpea/sunflower	Clover (full season) Cowpea/maize
Clover (full season) Cowpea/maize	Wheat Rice Fahl clover	Onion/sugar beet Cowpea/sunflower

Fig. 9.6 Suggested crop rotation in salt-affected soil of the first agro-climatic zone of Egypt in 2030

(Fig. 9.6). Fahl clover is a variety of Egyptian clover, which has stem branching ability, rapid growth, and large forage yield. The crop could only be cut once and it could be cultivated as early winter crop in September and stays until the beginning of November, where its growing season is between 60–70 days (Bakheit et al. 2016).

Moreover, in the third section of the rotation, cowpea intercropped with maize was implemented (Hamd-Alla et al. 2014). Detailed on this system is presented in Chap. 3.

The suggested crop rotation includes three intercropping systems and three-crop sequence, which will increase land productivity. It also contains a legume crop in each section, which will help in reducing soil degradation under expected climate change.

Water requirements for the crops exist in the prevailing and suggested crop rotations are presented in Table 9.8. It worth noting that leaching requirements for the cultivated crops were considered to be 10% of the applied irrigation water for each crop. The results in the table revealed that the amount of saved irrigation water, as a result of implementing the suggested rotation, will be 1717 m^3/ha, which represent 9% of the total applied water to the prevailing rotation.

Table 9.8 Water requirements for the expected prevailing and the suggested crop rotations in salt-affected soil of the first agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	5866	Onion/sugar beet	9449
Rice	13,326	Cowpea/sunflower	8267
Fahl clover	3347	Wheat	5265
Faba been/sugar beet	9946	Rice	12,660
Tomato	10,358	Fahl clover	2371
Clover (full season)	8717	Clover (full	7903
Maize	8393	Cowpea/maize	7360
	59,952		53,274
Water saving per hectare (m^3/ha) 2226			
Water saving (%) 11			

The Second Agro-climatic Zone

Crop Rotation in Sandy Soil

The prevailing crop rotation in the sandy soil of the second agro-climatic zone in Egypt is presented in Fig. 9.7. It contained a legume crop in each section, one intercropping system (maize intercropped with peanut (Sherif et al. 2005; see Chap. 7 for details), and a three-crop sequence.

The suggested crop rotation (Fig. 9.8) contains legume crops in each section. In sesame intercropped with peanut system, Abd El-Galil and Abd El-Ghany (2014) indicated that this system reduced the infection of root rot and wilt diseases. Under this system, peanut planting density is 100% of its recommended density and sesame density is 25% from its recommended planting density (Abou-Keriasha et al. 2008).

Year 1	Year 2	Year 3
Wheat Maize/peanut	Pea Sunflower Maize (late)	Clover (full season) Maize
Pea Sunflower Maize (late)	Clover (full season) Maize	Wheat Maize/peanut
Clover (full season) Maize	Wheat Maize/peanut	Pea Sunflower Maize (late)

Fig. 9.7 Expected prevailing crop rotation in the sandy soil of the second agro-climatic zones of Egypt in 2030

Year 1	Year 2	Year 3
Clover (full season) Sesame/peanut	Wheat/sugar beet Cowpea/maize	Wheat/tomato Sunflower/soybean
Wheat/tomato Sunflower/soybean	Clover (full season) Sesame/peanut	Wheat/sugar beet Cowpea/maize
Wheat/sugar beet Cowpea/maize	Wheat/tomato Sunflower/soybean	Clover (full season) Sesame/peanut

Fig. 9.8 Suggested crop rotation in sandy soil of the second agro-climatic zones of Egypt in 2030

Fig. 9.9 Wheat intercropping with sugar beet

The suggested rotation also includes sunflower intercropped with soybean. de la Fuentea et al. (2014) indicated that intercropping sunflower with soybean resulted in suppression of associated weeds and insects. The recommended planting density for this system should be 50% for both sunflower and soybean (El-Yamani et al. 2010).

In the third section of the rotation, wheat intercropped with sugar beet (Fig. 9.9). In this system, sugar beet is cultivated in October and wheat is intercropped on sugar beet 45 days later. Planting density of sugar beet is 100% and wheat planting density is 50%, which obtained the same yield of both crops as if they are planted solely. Wheat uses the applied irrigation water to sugar beet and both crops are harvest in April (Abou-Elela 2012). The advantage of this system is to increase the cultivated area of wheat by the percentage of the assigned area from sugar beet cultivated area. Furthermore, cowpea intercropped with maize system (Hamd-Alla et al. 2014) is also implemented.

Sprinkler or drip system is the prevailing irrigation systems in this type of soil. Table 9.9 indicated that the suggested rotation could save 1051 m^3/ha, which account for 6% of the total applied water to the prevailing rotation.

Table 9.9 Water requirements for the expected prevailing and the suggested crop rotations in sandy soil of the second agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	5438	Clover (full season)	7142
Maize/peanut	9166	Sesame/peanut	8707
Pea	3947	Wheat/tomato	4149
Sunflower (early)	6810	Sunflower/soybean	8628
Maize (late)	10,558	Wheat/sugar beet	10,537
Clover (full season)	7518	Cowpea/maize	9756
Maize	8638		
Total	52,074		48,920
Water saving per hectare(m^3/ha) 1051			
Water saving (%) 6			

Crop Rotation in Clay Soil

The expected prevailing rotation in the clay soil of the second agro-climatic zone is presented in Fig. 9.10. It contained a legume crop in each section, a three-crop sequence and one intercropping system, namely cotton relay intercropped on wheat (Zohry 2005). Details on the system are presented in Chap. 3.

In the first section of the suggested rotation (Fig. 9.11), faba bean intercropped with tomato (Fig. 9.12) will be implemented. Several advantages of intercropping faba bean with tomato are obtained, namely protection of tomato plants from abiotic stress (high or low temperatures). Furthermore, this system can increase the cultivated area of faba bean and consequently increase its production. Under this system, tomato seedlings are cultivated in the beginning of September, with 100% planting density, and faba bean is cultivated in October with 60% of recommended planting density. Both crops are harvested in the same date, which increases tomato season length by two months. Thus, this system increases the farmer's profit (Ibrahim et al. 2010).

Year 1	Year 2	Year 3
Wheat Maize Fahl clover	Cotton relay intercropped on wheat	Faba bean Maize/tomato
Cotton relay intercropped on wheat	Faba bean Maize/tomato	Wheat Maize Fahl clover
Faba bean Maize/tomato	Wheat Maize Fahl clover	Cotton relay intercropped on wheat

Fig. 9.10 Expected prevailing crop rotation in the clay soil of the second agro-climatic zone of Egypt in 2030

Year 1	Year 2	Year 3
Faba bean/tomato Sunflower/soybean	Cotton relay intercropped on wheat	Clover (full season) Soybean/maize
Clover (full season) Soybean/maize	Faba bean /tomato Sunflower/soybean	Cotton relay intercropped on wheat
Cotton relay intercropped on wheat	Clover (full season) Maize/soybean	Faba bean/tomato Sunflower/soybean

Fig. 9.11 Suggested crop rotation in the clay soil of the second agro-climatic zone of Egypt in 2030

Fig. 9.12 Faba bean intercropped on tomato system

In the second section of the rotation, cultivation of full season clover and intercropped soybean on maize system (Shrief and Gendy 2012, Chapter 3) will increase soil organic matter.

Relay intercropping cotton on wheat system could be implemented in the third section of the rotation (Zohry 2005, Chapter 3). Cultivation of the suggested cropping systems on raised beds will result in saving irrigation, in addition two saving two irrigation events for cotton when its relay intercropped with wheat.

Changing monoculture cultivation in the prevailing rotation to intercropping systems in the suggested rotation resulted in irrigation water saving. The saved amount was 1914 m^3/ha or 11% of the applied irrigation water to the prevailing crop rotation (Table 9.10).

Table 9.10 Water requirements for the expected prevailing and the suggested crop rotations in clay soil of the second agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	6041	Faba bean/tomato	4564
Maize	8532	Sunflower/soybean	9530
Fahl clover	3717	Clover (full season)	6785
Cotton/wheat	18,427	Soybean/maize	8106
Faba bean	5481	Cotton/wheat	17,506
Maize/tomato	10,032		
Total	52,231		46,490
Water saving per hectare (m^3/ha) 1914			
Water saving (%) 11			

The Third Agro-climatic Zone

Crop Rotation in Salt-Affected Soil

The prevailing crop rotation in salt-affected soil of the third agro-climatic zone is presented in Fig. 9.13. It contained one intercropping system, three-crop sequence, and two-crop sequence. It also contained two legume crops.

Regarding the suggested crop rotation (Fig. 9.14), it contained three intercropping systems and two legume crops, namely fahl clover and clover to improve soil quality.

Water requirements for prevailing and suggested crop rotations in salt affected are presented in Table 9.11. The results in that table indicated that 1101 m^3/ha or 5% saving in the applied irrigation water to the prevailing rotation.

Year 1	Year 2	Year 3
Cotton relay intercropped on wheat	Sugar beet Rice Fahl clover	Clover (full season) Maize
Sugar beet Rice Fahl clover	Clover (full season) Maize	Cotton relay intercropped on wheat
Clover (full season) Maize	Cotton relay intercropped on wheat	Sugar beet Rice Fahl clover

Fig. 9.13 Expected prevailing crop rotation in the salt-affected soil of the third agro-climatic zone of Egypt in 2030

Year 1	Year 2	Year 3
Faba bean/sugar beet Cowpea/sunflower	Clover (full season) Maize/tomato	Wheat Rice Fahl clover
Wheat Rice Fahl clover	Faba bean/sugar beet Cowpea/sunflower	Clover (full season) Maize/tomato
Clover (full season) Maize/tomato	Wheat Rice Fahl clover	Faba bean/sugar beet Cowpea/sunflower

Fig. 9.14 Suggested crop rotation in the salt-affected soil of the third agro-climatic zone of Egypt

Table 9.11 Water requirements for the expected prevailing and the suggested crop rotations in salt-affected soil of the third agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Cotton/wheat	17,459	Faba bean/sugar beet	9221
Sugar beet	9707	Cowpea/sunflower	8423
Rice	13,348	Wheat	8981
Fahl clover	4205	Rice	12,681
Clover (full season)	9964	Fahl clover	3995
Maize	11,452	Clover (full season)	9466
		Maize/tomato	10,066
Total	66,135		62,833
Water saving per hectare (m^3/ha) 1101			
Water saving (%) 5			

Crop Rotation in Clay Soil

The expected prevailing crop rotation in the clay soil of the third agro-climatic zone is presented in Fig. 9.15.

In the suggested crop rotation (Fig. 9.16), wheat is intercropped with tomato and maize is intercropped with soybean in the first section. Clover and cowpea intercropped with sunflower are cultivated. In the third section, cotton is relay intercropped with onion.

Table 9.12 showed that the applied irrigation water to the suggested rotation will be lower than the applied amounts to the prevailing rotation. Implementing the suggested crop rotation could save 2143 m^3/ha, which amount to 11% of the applied water to the prevailing rotation.

Year 1	Year 2	Year 3
Wheat Maize Fahl clover	Clover (full season) Soybean (early) Sunflower	Cotton relay intercropped on onion
Clover (full season) Soybean (early) Sunflower	Cotton relay intercropped on onion	Wheat Maize Fahl clover
Cotton relay intercropped on onion	Wheat Maize Fahl clover	Clover (full season) Soybean (early) Sunflower

Fig. 9.15 Expected prevailing crop rotation in the clay soil of the third agro-climatic zone of Egypt in 2030

Year 1	Year 2	Year 3
Wheat/tomato Maize/soybean	Cotton relay intercropped on onion	Clover (full season) Sunflower/soybean
Clover (full season) Cowpea/sunflower	Wheat/tomato Maize/soybean	Cotton relay intercropped on onion
Cotton relay intercropped on onion	Clover (full season) Sunflower/soybean	Wheat/tomato Maize/soybean

Fig. 9.16 Suggested crop rotation in the clay soil of the third agro-climatic zone of Egypt in 2030

Table 9.12 Water requirements for the expected prevailing and suggested crop rotations in clay soil of the third agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Wheat	6875	Wheat/tomato	5746
Cowpea/maize	10,412	Maize/soybean	11,606
Clover (full season)	9057	Clover (full season)	8604
Soybean (early)	6203	Cowpea/sunflower	8866
Sunflower (late)	7791	Cotton/onion	17,353
Cotton/onion	18,266		
Total	58,604		52,175
Water saving per hectare (m^3/ha) 2143			
Water saving (%) 11			

The Fourth Agro-climatic Zone

Crop Rotation in Sandy Soil

The prevailing crop rotation in the sandy soil of the fourth agro-climatic zone is similar to the one existed in the second agro-climatic zone with one difference; namely, maize is replaced by sorghum (Fig. 9.17).

Year 1	Year 2	Year 3
Clover (full season) Sesame	Wheat Peanut Fahl clover	Faba bean Cowpea/sorghum
Wheat Peanut Fahl clover	Faba bean Cowpea/sorghum	Clover (full season) Sesame
Faba bean Cowpea/sorghum	Clover (full season) Sesame	Wheat Peanut Fahl clover

Fig. 9.17 Expected prevailing crop rotation in the sandy soil in the fourth agro-climatic zone of Egypt in 2030

Year 1	Year 2	Year 3
Clover (full season) Maize/peanut	Faba bean/sugar beet Cowpea/sorghum	Wheat/tomato Maize/soybean
Wheat/tomato Maize/soybean	Clover (full season) Maize/peanut	Faba bean/sugar beet Cowpea/sorghum
Faba bean/sugar beet Cowpea/sorghum	Wheat/tomato Maize/soybean	Clover (full season) Maize/peanut

Fig. 9.18 Suggested crop rotation in the sandy soil in the fourth agro-climatic zone of Egypt in 2030

Table 9.13 Water requirements for the expected prevailing and suggested crop rotations in sandy soil of the fourth agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	7403	Clover (full season)	7033
Sesame	11,036	Maize/peanut	8554
Wheat	6954	Wheat/tomato	7442
Peanut	9004	Maize/soybean	8453
Fahl clover	3784	Faba bean/sugar beet	8908
Faba bean	7930	Cowpea/sorghum	10,431
Cowpea/sorghum	10,980		
Total	49,689		43,787
Water saving per hectare (m^3/ha) 1967			
Water saving (%) 12			

The suggested crop rotation will include intercropping systems to improve soil characteristics. It contained five intercropping systems in addition to clover (Fig. 9.18).

Implementing the suggested crop rotation in the sandy soil of the fourth agro-climatic zone could result in saving in the applied irrigation water for the prevailing crop rotation by 12%, which amount for 1967 m^3/ha (Table 9.13).

Crop Rotation in Clay Soil

The crops cultivated in the prevailing crop rotation contained two legume crops, namely full season clover and faba bean. Furthermore, sorghum is preceded by wheat, where both are cereal crops (Fig. 9.19).

The suggested crop rotation could increase land and water productivity as a result of implementing various intercropping systems (Fig. 9.20). The rotation included four intercropping systems, in addition to clover and wheat.

Irrigation water saving of 1983 m^3/ha could be attained when the suggested rotation implemented. This amount represents 10% of the applied water to the prevailing crop rotation (Table 9.14).

The Fifth Agro-climatic Zone

Crop Rotation for Sugarcane

Crop rotation in the fifth agro-climatic zone is called sugarcane rotation because sugarcane is the main crop in it. In this rotation, sugarcane occupies one half of its area. It contains six sections and implemented in eight years, where there are two preliminary years. These two preliminary years allow the farmers to produce new cane every year to produce good quality sugarcane.

Year 1	Year 2	Year 3
Clover (full season) Sunflower/tomato	Wheat Sorghum Fahl clover	Faba bean Soybean/maize
Wheat Sorghum Fahl clover	Faba bean Soybean/maize	Clover (full season) Sunflower/tomato
Faba bean Soybean/maize	Clover (full season) Sunflower/tomato	Wheat Sorghum Fahl clover

Fig. 9.19 Expected prevailing crop rotation in the clay soil in the fourth agro-climatic zone of Egypt

Year 1	Year 2	Year 3
Clover (full season) Sunflower/tomato	Faba bean/sugar beet Maize/tomato	Wheat Cowpea/sorghum
Wheat Cowpea/sorghum	Clover (full season) Sunflower/tomato	Faba bean/sugar beet Maize/tomato
Faba bean/sugar beet Maize/tomato	Wheat Cowpea/sorghum	Clover (full season) Sunflower/tomato

Fig. 9.20 Suggested crop rotation in the clay soil in the fourth agro-climatic zone of Egypt

Table 9.14 Water requirements for the expected prevailing and suggested crop rotations in clay soil of the fourth agro-climatic zone in 2030

Prevailing rotation	Water requirements (m^3/ha)	Suggested rotation	Water requirements (m^3/ha)
Clover (full season)	7546	Clover (full season)	6810
Sunflower/tomato	11,546	Sunflower/tomato	10,420
Wheat	6494	Wheat	5861
Sorghum	10,534	Cowpea/sorghum	9507
Fahl clover	3819	Faba bean/sugar beet	8462
Sugar beat	5774	Maize/tomato	10,420
Soybean/maize	10,200		
Total	7546		51,481
Water saving per hectare (m^3/ha) 1983			
Water saving (%) 10			

In the first preliminary year, new cane introduced in the rotation, whereas in the second preliminary year, the 1st ratoon is produced from the cane cultivated in the first preliminary year, and new cane is introduced in the underneath section. In the first year of the rotation, 2nd ratoon is produced from the 1st ratoon cultivated in the second preliminary year, and new cane is introduced in the underneath section. This procedure continues to the end of the rotation. Thus, in the first year of the rotation and after the two preliminary years, new canes, 1st ratoon and 2nd ratoon, exist in each year.

The Fall Sugarcane Crop Rotation

The fall sugarcane is cultivated in September and October and harvested after 16 months. As we stated before, we assumed that sugarcane irrigation will be done using gated pipes to reduce the 10% of irrigation water during its long growing season by 10%. Furthermore, the expected prevailing fall will include intercropping systems with sugarcane, namely with faba bean, onion, or wheat (Fig. 9.21).

In the suggested fall rotation (Fig. 9.22), fallow is preceding the new cane because sugarcane is planted in September and the preceding summer crops are usually harvested in May. Furthermore, either faba bean (Farghly 1997), onion (Zohry 1997), or wheat (Ahmed et al. 2013) will be intercropped on the new cane. Details of these systems are presented in Chap. 8.

Besides intercropping systems with sugarcane, intercropping systems could be implemented for summer crops. Cowpea could be intercropped with sorghum and sunflower. Soybean intercropped with sorghum system (Abou-keriasha et al. 1993) could be implemented. Additionally, sole planting could be implemented for wheat, clover, and sorghum.

First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Fallow Faba bean/new cane	1stRatoon
Faba bean Sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Onion/new cane
Wheat Sorghum	Lentil Sorghum	Fallow Wheat/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Fallow Wheat/new cane	1stRatoon	2ndRatoon

Fig. 9.21 Expected prevailing fall sugarcane crop rotation in the fifth agro-climatic zone of Egypt in 2030

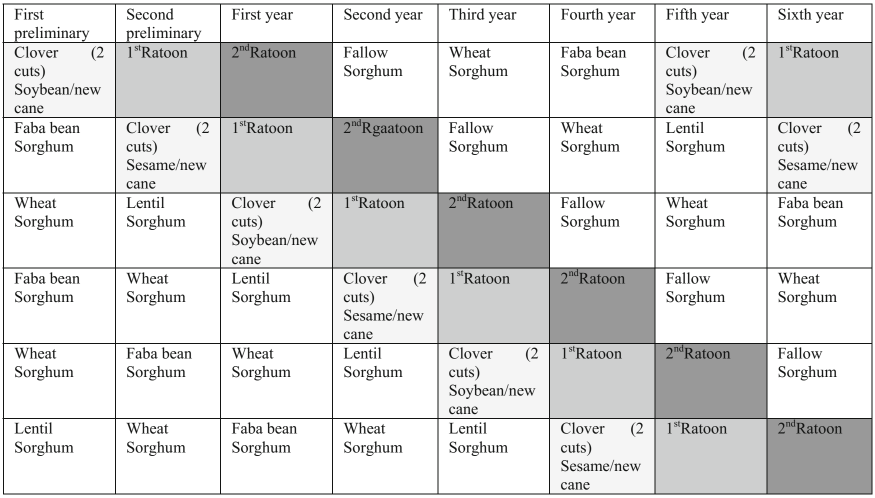
First Preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Fallow faba bean/new cane	1stRatoon	2ndRatoon	Faba bean Soybean/sorghum	Wheat Soybean/maize	Faba bean Cowpea/sorghum	Fallow Faba bean/new cane	1stRatoon
Faba bean Cowpea/sorghum	Fallow Onion/new cane	1stRatoon	2ndRatoon	Faba bean Cowpea/sunflower	Wheat Soybean/maize	Faba bean Soybean/sorghum	Fallow Onion/new cane
Wheat Cowpea/sorghum	Faba bean Cowpea/sorghum	Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Clover Sorghum	Wheat Soybean/maize	Faba bean Cowpea/sorghum
Clover Sorghum/soybean	Wheat Cowpea/sunflower	Lentil Soybean/maize	Fallow Onion/new cane	1stRatoon	2ndRatoon	Clover Cowpea/sorghum	Wheat Soybean/maize
Wheat Cowpea/Sunflower	Clover Soybean/sorghum	Wheat Cowpea/maize	Clover Cowpea/maize	Fallow Faba bean/new cane	1stRatoon	2ndRatoon	Clover Cowpea/sunflower
Lentil Soybean/Sorghum	Wheat Cowpea/sorghum	Clover Soybean/Maize	Wheat Soybean/sorghum	Clover Cowpea/maize	Fallow Onion/new cane	1stRatoon	2ndRatoon

Fig. 9.22 Suggested fall sugarcane crop rotation in the fifth agro-climatic zone of Egypt in 2030

Including intercropping systems for sugarcane rotation could be consumed the same amount of irrigation water required water under sugarcane monoculture in 2030 under climate change. Furthermore, including intercropping systems for the cultivated crops in the rotation increased its number from 88 crops in the expected prevailing rotation to 112 crops in the suggested rotation, in addition to save 10% of the applied water to the suggested rotation as a result of using gated pipes for irrigation. Thus, the suggested fall sugarcane rotation could consume 1,919,611 m^3 of water to irrigate 78 crops, compared to 2,132,901 m^3 consumed by the expected prevailing crop rotation to irrigate 110 crops (Table 9.15).

Table 9.15 Water requirements for the expected prevailing and suggested fall sugarcane rotations in the fifth agro-climatic zone of Egypt in 2030

	Prevailing fall rotation		Suggested fall rotation	
	Total amount (m^3)	No. of cultivated crops	Total amount (m^3)	No. of cultivated crops
First preliminary	219,026	12	197,123	17
Second preliminary	252,435	11	227,192	15
First year	284,885	10	256,397	13
Second year	275,243	9	247,719	13
Third year	275,243	9	247,719	13
Fourth year	275,413	9	247,871	13
Fifth year	275,243	9	247,719	13
Sixth year	275,413	9	247,871	13
Total	2,132,901	78	1,919,611	110

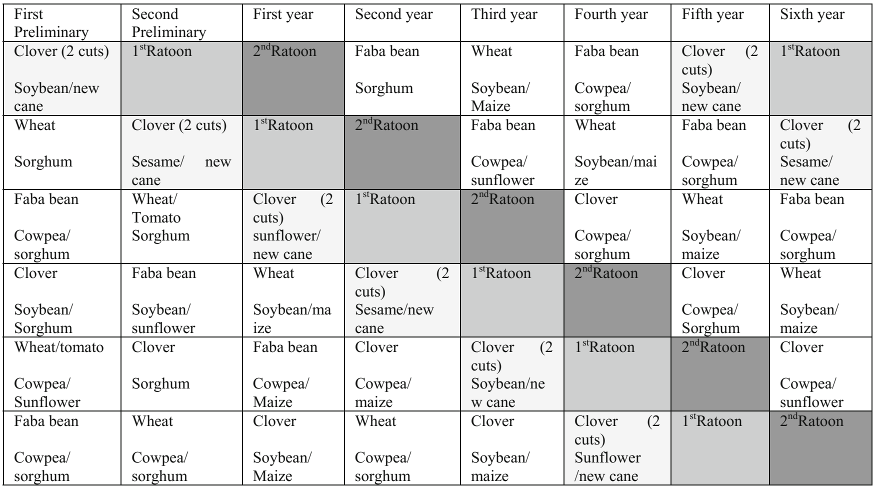


First preliminary	Second preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum	Clover (2 cuts) Soybean/new cane	1stRatoon
Faba bean Sorghum	Clover (2 cuts) Sesame/new cane	1stRatoon	2ndRgaatoon	Fallow Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sesame/new cane
Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum	Faba bean Sorghum
Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sesame/new cane	1stRatoon	2ndRatoon	Fallow Sorghum	Wheat Sorghum
Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Fallow Sorghum
Lentil Sorghum	Wheat Sorghum	Faba bean Sorghum	Wheat Sorghum	Lentil Sorghum	Clover (2 cuts) Sesame/new cane	1stRatoon	2ndRatoon

Fig. 9.23 Expected prevailing spring sugarcane crop rotation in the fifth agro-climatic zone of Egypt in 2030

The Spring Sugarcane Rotation

The spring sugarcane (Fig. 9.23) is cultivated in February and March and harvested after 12 months. The expected prevailing spring sugarcane rotation will include sugarcane intercropping systems with soybean (Abou-Keriasha et al. 1997), sesame (Abou-Keriasha et al. 1997), or sunflower (El-Gergawi et al. 2000). Details of these systems are presented in Chap. 8.



First Preliminary	Second Preliminary	First year	Second year	Third year	Fourth year	Fifth year	Sixth year
Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Faba bean Sorghum	Wheat Soybean/ Maize	Faba bean Cowpea/ sorghum	Clover (2 cuts) Soybean/ new cane	1stRatoon
Wheat Sorghum	Clover (2 cuts) Sesame/ new cane	1stRatoon	2ndRatoon	Faba bean Cowpea/ sunflower	Wheat Soybean/maize	Faba bean Cowpea/ sorghum	Clover (2 cuts) Sesame/ new cane
Faba bean Cowpea/ sorghum	Wheat/ Tomato Sorghum	Clover (2 cuts) sunflower/ new cane	1stRatoon	2ndRatoon	Clover Cowpea/ sorghum	Wheat Soybean/ maize	Faba bean Cowpea/ sorghum
Clover Soybean/ Sorghum	Faba bean Soybean/ sunflower	Wheat Soybean/maize	Clover (2 cuts) Sesame/new cane	1stRatoon	2ndRatoon	Clover Cowpea/ Sorghum	Wheat Soybean/ maize
Wheat/tomato Cowpea/ Sunflower	Clover Sorghum	Faba bean Cowpea/ Maize	Clover Cowpea/ maize	Clover (2 cuts) Soybean/new cane	1stRatoon	2ndRatoon	Clover Cowpea/ sunflower
Faba bean Cowpea/ sorghum	Wheat Cowpea/ sorghum	Clover Soybean/ Maize	Wheat Cowpea/ sorghum	Clover Soybean/ maize	Clover (2 cuts) Sunflower /new cane	1stRatoon	2ndRatoon

Fig. 9.24 Suggested spring sugarcane crop rotation in the fifth agro-climatic zone of Egypt in 2030

In the spring sugarcane rotation (Fig. 9.24), wheat could be cultivated either monoculture or intercropped with tomato. Clover and faba bean are cultivated as monoculture. Intercropping with new sugarcane could be implemented, where soybean or sesame are intercropped. Intercropping sesame with spring sugarcane system can be implemented (Fig. 9.24).

The expected prevailing spring sugarcane rotation in 2030 (Table 9.16), the 86 crops cultivated in it consumed 1,991,164 m^3 of irrigation water, whereas the suggested spring sugarcane rotation consumed 1,792,048 m^3 of irrigation water by 117 crops cultivated in it. Thus, the suggested rotation has higher water productivity and land productivity.

Conclusion

The adverse consequences of climate change on land productivity, water productivity, and soil fertility could be diminished by implementing crop rotations. Our results revealed that increasing number of crops within the rotation by implementing intercropping systems in both growing seasons, as well as three-crop sequences could reduce the loss in the productivity of the associated crops in the rotation under climate change. Using improved management packages to reduce the applied irrigation water to the cultivated crops could compensate the increase in crops water requirements under climate change. Furthermore, the inclusion of legume crops in each section of the rotation could prevent soil degradation under climate change.

Table 9.16 Water requirements for the prevailing and suggested spring sugarcane rotations in the fifth agro-climatic zone of Egypt

	Prevailing spring rotation		Suggested spring rotation	
	Total amount (m^3)	No. of cultivated crops	Total amount (m^3)	No. of cultivated crops
First preliminary	200,887	13	180,799	18
Second preliminary	234,593	12	211,133	15
First year	267,330	11	240,597	14
Second year	257,602	10	231,842	14
Third year	257,602	10	231,842	14
Fourth year	257,773	10	231,996	14
Fifth year	257,602	10	231,842	14
Sixth year	257,773	10	231,996	14
Total	1,991,164	86	1,792,048	117

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